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SOME PROBLEMS OF SOLID AND LIQUID WASTE DISPOSAL IN THE NORTHERN ENVIRONMENT

A series of 8 reports by

Technical Branch,
Environment Protection Service,
Department of the Environment
Northwest Region

and

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The data for these reports were obtained as a result of investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is also useful in planning and assessing highways and other development projects.

The research was carried out and the report was prepared under contract for the Arctic Land Use Research Program, Northern Natural Resources and Environment Branch, Department of Indian Affairs and Northern Development. The views, conclusions and recommendations expressed herein are those of the authors and not necessarily those of the Department.

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REFUSE SACK COLLECTION
SYSTEM STUDY

by

K. R. Heuchert

Technical Branch
Environmental Protection Service
Northwest Region
Environment Canada

March 1974

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1. SUMMARY

This investigation was concerned with determining the acceptability of the refuse sack collection system for use in the North. The study was carried out at Aklavik and Wrigley, N.W.T.

A number of difficulties were encountered during the study, resulting in Aklavik abandoning the project almost immediately after start-up and Wrigley discontinuing the use of the sack system approximately four months after start-up.

One of the main reasons for the project abandonments was that the residents of the two settlements could see no advantage to the refuse sack collection system over the previous collection methods. The two communities had well-managed collection systems before the refuse sack project was initiated.

2. INTRODUCTION

The collection of domestic refuse is probably the most difficult phase of the solid waste problem in the Canadian North.

Costs that might be incurred in northern communities, compared to southern communities, are probably much higher. This can be partially attributed to the harshly adverse winter conditions in the North which make the pick-up and transportation of refuse very difficult.

At present, in most communities, domestic refuse is deposited in garbage cans or 45-gallon drums prior to pick-up. During winter months refuse tends to freeze to these containers, making the work of the collection personnel all the more difficult. There is also a tendency for these containers to become the focal point for congregations of dogs and ravens, thus resulting in the refuse being scattered over relatively large areas and adding to the already difficult problem of collection.

A health hazard may also be created, in particular, when sewage bags are a part of domestic refuse, as is the case in many northern communities.

At most northern work camps, refuse is stored in large garbage cans, lined with plastic bags. When these containers become full, the plastic bags are removed and new ones inserted. These bags, containing the refuse, are then incinerated. There can be a problem if the refuse is stored outdoors prior to incineration. During winter the plastic becomes brittle and easily ruptured.

The refuse sack collection system offers a feasible alternative to those methods being employed at present. Its potential for use in the overall waste management program at a pipeline construction camp was discussed in the report "Management of Waste from Arctic and Sub-Arctic Work Camps" by Grainge *et al* (1973).

In order to evaluate the usefulness of large paper sacks in replacing garbage cans and barrels, a small project was set up in two communities, Aklavik and Wrigley, N.W.T. Holders for the refuse sacks were attached to approximately twenty homes in each of the two communities.

The main objective of the study was to determine the overall acceptability of replacing metal containers with wet strength paper refuse sacks in northern Canada. The acceptability was related to:

(a) handling,
(b) aesthetics,
(c) personal preference.

It was anticipated that this study would be very useful in determining the acceptability of the refuse sack system for northern work camps. Pipeline work camps in the Mackenzie Valley are expected to have populations of up to and possibly greater than 600 people. This is the approximate size of Aklavik, N.W.T.

These small industrial communities will require a sound solid waste management program, part of which will be an acceptable in-house storage and collection procedure. The paper refuse sack collection system is one alternative which should be considered.

3. CURRENT STATE OF KNOWLEDGE

Large paper refuse sacks are commonly used for domestic refuse in such places as Greenland, Denmark, Norway, Sweden, Finland and England. Grainge (1969, 1974) has indicated that this method of in-house storage works very well and is totally acceptable.

These refuse sacks are approximately 1/3 cubic metres in size and are either hung from holders attached to the exterior of the homes or fitted into compartments accessible from both inside and outside the residence. Figures 1 to 3 show typical holder and bag set-ups in Greenland.

Domestic refuse is generally hauled in open trucks in Greenland, which is the same as that method used in northern Canada.

An extensive study was carried out for the City of Inglewood, California, by Stone and Company Inc. (1972). The results of that study indicated a general acceptability of the refuse sack collection system.

Refuse sack collection systems of this type have not previously been used in northern Canada.

Figure 1

Figure 2

Standard plastic-impregnated, double thickness, paper garbage bags, which will withstand rain. In the best arrangement, the bag fits into compartment of house which is accessible by air-tight trap from inside and by door from outside. (after Grainge, 1969)

Figure 3

Typical Cleanup at Residence
(Note garbage container with
metal lid.) (after Grainge, 1969)

4. STUDY AREAS

Through the assistance of the Department of Local Government, Government of the Northwest Territories, Department of National Health & Welfare, Yellowknife, N.W.T. and Department of Public Works, Government of the Northwest Territories, two communities were chosen for the pilot project. One of the conditions in choosing the sites was that the settlement managers have a genuine interest in the project. With this in mind, the two communities, Wrigley and Aklavik, were chosen. Approximately twenty homes in each community participated in the study.

Wrigley is a settlement located along the east bank of the Mackenzie River approximately 114 air miles north of Fort Simpson at 63°13'N latitude and 123°23'W longitude. The population of Wrigley is approximately 200. Hunting, trapping and fishing are the basis of the economy of the settlement. The community also has a small saw mill.

The residents of Wrigley were using 45 gallon drums for refuse storage and burning prior to pickup. The refuse disposal area is a small dump site, just outside the town. Pit privies are common, resulting in no sewage bags being disposed of with the refuse.

The study was initiated at Wrigley in July, 1973.

Aklavik, the second community chosen for the study, has an approximate population of 600 and is located 35 air miles west and south of Inuvik on the west shore of the Peel Channel at 68°12' N latitude and 135°00' W longitude. Fur production and manufacture of fur garments and handicrafts are the main economic base of the settlement.

Sewage bags and domestic refuse are picked up and hauled on a contract basis to a dump site.

The refuse sack study was initiated at Aklavik in August, 1973.

Two types of refuse sacks were used at the two settlements for this investigation.

1. Galvanized holders with 2-holed bracket for securing to the sides of houses or backyard fences (11 1/2" wide x 16" long). Jaw type clamp for securing paper bag to holder.

2. Bag Types: (i) 26" x 42 3/4" pasted open mouth 2/60 wet strength paper.

   (ii) 26" x 42 3/4" x 10" pasted open mouth 2/60 wet strength paper with 1 1/2 mil free film liner 26" x 49" inserted and cut flush with bag length.

3. Printing: Refuse Sack System. Pilot Project by Department of Local Government, N.W.T. and Environment Canada, Environmental Protection Service, Northwest Region.

The refuse sacks were purchased from Consolidated Bathurst Packaging Ltd., Calgary, Alberta.

Figure 4 is a schematic diagram of the holder and refuse sack arrangement. Figures 5 and 6 are photographs of holders and sacks installed at Aklavik, N.W.T.

REFUSE SACK HOLDER

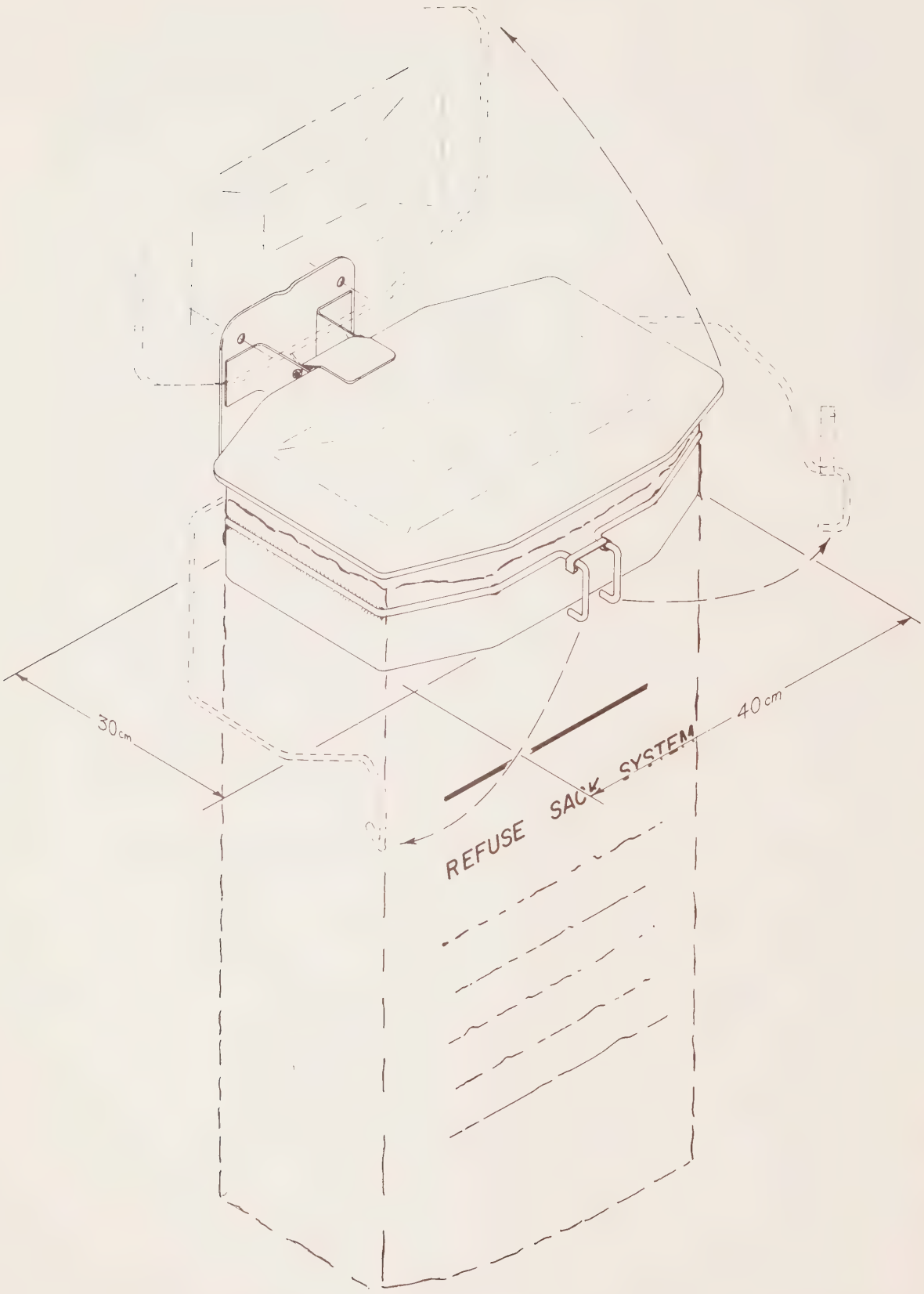

FIGURE 4

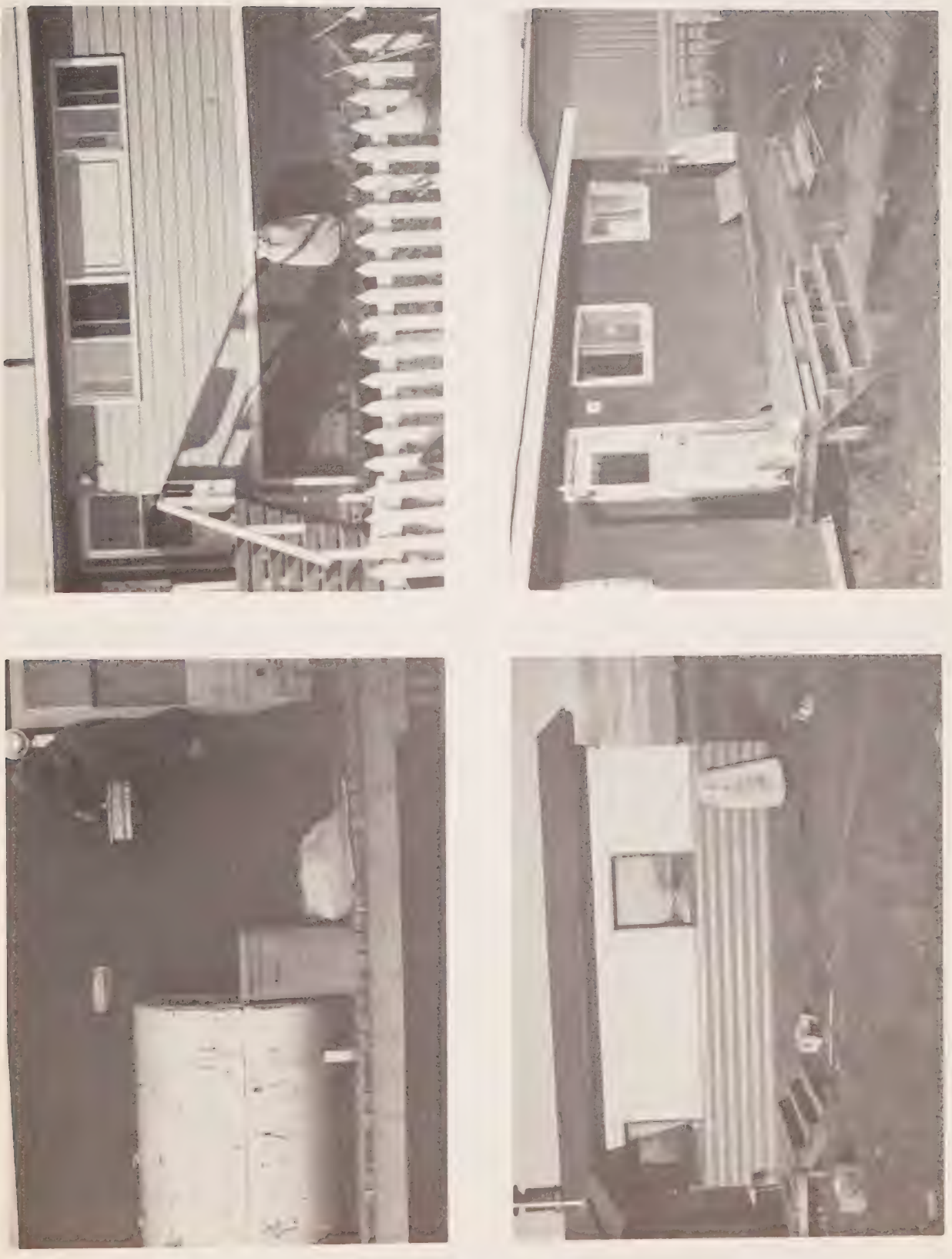

Figure 5 - Holders and bags attached to homes in Aklavik, N.W.T.

Figure 6 - Holders and bags attached to homes in Aklavik, N.W.T.

5. METHODS AND SOURCES OF DATA

The pilot study results were strictly subjective. The most valuable information was obtained from the settlement managers since they are in charge of the operations of the settlements. The views of the refuse collection personnel were also of great importance, for obvious reasons.

The settlement manager, settlement secretary, collection personnel and study participants in Wrigley were contacted approximately two months after the study was initiated. An Environmental Protection Service employee also visited the community during March, 1974. The Aklavik settlement manager, settlement secretary, settlement chairman, councillors, collection personnel and members of some of the participating families were contacted during February, 1974. Earlier contacts with the settlement manager during 1973 had also been made.

6. RESULTS

6.1 Aklavik

Shortly after the study was initiated at Aklavik the project was abandoned by the settlement.

The reasons given for discontinuing the use of the refuse sack collection system were as follows:

1. There was a conflict of interest between the refuse and sewage hauling contractors. (An attempt had been made to combine the two collection activities.) The solid waste hauling contractor would not collect refuse sacks containing sewage bags and likewise with the sewage hauling contractor because the refuse sacks containing sewage bags also contained dry garbage. This led to a stalemate and as a result several bags were still full, six months later, hanging from the holders.

2. The residents did not like the holders attached to the sides of the homes. They thought it would be better to have the bags in containers at the edge of the street. There were also complaints that the holders were placed too high for easy access, or were not fastened properly and therefore did not remain attached to the homes. The latter was probably due to children hanging on them, in the opinion of the settlement manager.

3. The settlement felt the project had been forced upon them.

6.2 Wrigley

On September 28, 1973, two months after the study initiation, a questionnaire was prepared. These were filled out individually by a representative of the Environmental Protection Service during personal interviews at each of the residences.

The Wrigley residents had the opportunity of using both types of bags. The bags were replaced by the collection personnel so the type of bag used depended solely on what the collection men distributed.

The following is a brief summary of the pertinent questions asked and the answers received during the September visit.

Question 1. Do you prefer this method of collection over the method used before?

Pro: 50%
Con: 50%
Comment: Most who wished to continue this type of garbage collection, provided no reason to support their opinion.

Question 2. Comment on the size of bags.

a)	much too large	0%
b)	too large	0%
c)	right size	40%
d)	too small	60%
e)	much too small	0%

Comment: 85% of the people who wanted to discontinue the paper bag study said the bags were too small for their purposes. 70% of the people who wanted to continue using the paper bags said the bags were the right size.

Question 3. Are the bags strong enough?

Only one person out of fourteen was dissatisfied with the strength of the bag whether it be wet strength or polyethylene lined.

Question 4. Approximately how many bags have been damaged or broken?

35% of the total people interviewed reported no damaged or torn bags.
The remaining participants stated that they had experienced one or two incidents of torn bags.

Question 5. What difficulties have you experienced with using refuse bags for storage and collection?

a) Children play with the bags and tear them.
b) Contradictory comments on dogs tearing the bags but no actual occurrences. There were some comments on dogs not being able to smell through plastic.
c) One interviewed person simply said he did not like the paper bag.
d) Difficult to dispose of cardboard boxes and bulky items of this nature.
e) Placing the holders higher from the ground would place the bags out of reach of the dogs; however, the bags would then be inaccessible to the user.

Summary of the Settlement Manager and Refuse Collectors, both sharing the same opinion:

The frequency of collection (twice per week) had not changed with the introduction of the new system. Cleanliness of the yards had not improved or degenerated as a result of the paper bag system. The streets were aesthetically more appealing as a result of the removal of the 45 gallon barrels. Space requirements for the landfill site had not changed as the new system was introduced. Ease of handling of the garbage had improved.

During November, 1973, the settlement council decided to discontinue the use of the refuse sack system. Their reasons for ending the investigation were as follows:

1. The bags were being torn by dogs resulting in refuse being strewn around the yards. The end condition was more objectionable than when the 45 gallon drums were being used.

2. The bag system was not necessary because Wrigley has always been a tidy community and garbage collection and disposal was not a problem.

The observations of the Environmental Protection Service employee who visited Wrigley in March 1974 were that the barrel system of storage and pickup was working very well. The barrels were along the roadside away from the homes. The yards were very clean and there did not appear to be any problem with refuse being scattered around.

7. DISCUSSION

The abandonment of the pilot project at Aklavik indicates that the approach taken for evaluating this system was unacceptable. It is the opinion of the author that there were two basic reasons for the project termination:

1. The residents did not feel that they were involved in the study.

2. It is very difficult to propose changes to existing ways of life and expect the people concerned to accept these changes immediately.

The Wrigley study did prove that the system will work. They did not have any major difficulties until approximately four months after the study initiation.

Unfortunately, when the use of the refuse sack system was abandoned in both Aklavik and Wrigley, no one within the Environmental Protection Service was notified of the difficulties the communities were experiencing. Perhaps the problems could have been overcome. The author is confident that if the Territorial Government had been responsible for the investigation, the project would not have terminated in the manner in which it did. A better response would probably be obtained if the Territorial Government was responsible for the project, relying only on the Environmental Protection Service for advisory support.

The residents of Aklavik and Wrigley have decided that they would rather use the 45 gallon drums instead of the bag system. It is therefore impossible to reinstate the project in either of these communities.

The author believes that the refuse sack collection system, if implemented in the North, would be a great improvement over the collection systems presently being used in most communities. The greatest problem is trying to overcome an established practice. Serious consideration should be given to implementing in-house refuse sack storage systems when designing new northern homes.

The introduction of the refuse sack system into a pipeline construction camp would be relatively simple as compared to instating it in an established community. Pipeline camps would require careful planning concerning waste management and servicing. Because these communities will be constructed anew, it would be very simple to include the refuse sack system in the overall program of solid waste handling.

8. CONCLUSIONS

1. There must be a genuine interest on the part of the users of the refuse sack system in order for it to work.

2. The Aklavik and Wrigley residents could see no advantage in the refuse sack system over the existing systems.

3. The problems encountered to date in the settlements are unlikely to exist at northern work camps.

4. Bulky items such as cartons should be placed separately beside the garbage as is common in most of Canada. For example, an empty carton could be filled with garbage and placed beside the bag.

5. The Government of the Northwest Territories should be responsible for future refuse sack studies at northern communities, relying on Environmental Protection Service staff for technical support only.

9. IMPLICATIONS AND RECOMMENDATIONS

In designing and constructing new residences and services for pipeline construction camps, in-house facilities to accommodate the use of the refuse sack system should be considered as a part of the overall waste management program.

10. NEED FOR FURTHER STUDY

The refuse sack system should be evaluated at a northern work camp.

11. REFERENCES

Grainge, J.W., 1974, Personal communications.

Grainge, J.W., Edwards, R., Heuchert, K.R., and Shaw, J.W., 1973, Management of Waste from Arctic and Sub-Arctic Work Camps; Report No. 73-19 for the Environmental Social Committee, Northern Pipeline, Task Force on Northern Oil Development.

Grainge, J.W., November 12, 1969, Study of Environmental Engineering in Greenland and Iceland; Manuscript Report No. NR-69-5, sponsored by the World Health Organization.

Stone and Company Inc., 1972, The Use of Bags for Solid Waste Storage and Collection, prepared for Environmental Protection Agency, distributed by National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Va. 22151.

WORK CAMPS SEWAGE DISPOSAL
WASHCAR - INCINERATION COMPLEX

by

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Environmental Protection Service
Environment Canada

March, 1974

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APPENDIX I*

* Available on request to Manager, A.L.U.R. Program, N.N.R&E. Br. Dept. Indian & Northern Affairs, Ottawa, K1A OH4

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1. SUMMARY

The workcamp sewage disposal study outlined in this report investigates an alternative to conventional methods of sewage collection and disposal for northern camps. This method of sewage treatment will be of primary importance in areas where water supplies are limited or in areas such as high ice content permafrost zones, where the construction of sewage lagoons is undesireable.

The complete system is composed of two portable trailer units connected by a utilidor. The first trailer is a washcar containing vacuum and chemical recirculating toilets, urinals, washbasins, showers, clothes washers, driers, a sauna, and ancillary equipment. The second trailer houses the sewage holding tank, incinerator and associated equipment. Liquid wastes are collected by the vacuum and recirculating toilet systems and pumped to a holding tank in concentrated form. Contents of the holding tank are then discharged to the incinerator for high temperature combustion.

Results of the study to date show the water consumption of the vacuum toilets to be approximately 1.5 litre/flush, considerably less than the 15-25 litres used in conventional units. It was found that the vacuum and chemical recirculating toilets saved approximately 22,500 litres of water per month, and limited the total monthly water consumption to 51,500 litres for the period under study. However, the showers and washing machines consumed most of the total water supply and future studies are required to investigate methods for further water conservation in these areas.

Certain drawbacks are inherent in the system, such as the high cost of self-sufficiency involved with electrical power generation and requirements for supervisory personnel for maintenance, repair and sewage incineration.

From the initial stages of the study, it is thought that the system is a feasible alternative to conventional means of sewage treatment, and further studies are required to determine user response and equipment capabilities over an extended time period. Also, tests concerning incinerator operating efficiency and stack emissions have not yet been concluded.

2. INTRODUCTION

2.1 Nature and scope of study

At present, the methods of wastewater collection and disposal used for construction camps in the N.W.T. are basically of two types, sewage lagoons and trucked systems for holding tank wastes. There are inherent drawbacks to both of these methods. The applicability of a sewage lagoon is dependent upon specific site conditions. Such factors as availability of fill material for berm construction, drainage patterns, depth of the water table and soil permeability, must be suitable for lagoon construction. In areas of permafrost, lagooning may be further complicated by the presence of ice wedges or high ice content soils, and by the problem of thermokarst development. The disposal of effluents may also be a problem and the reclamation of abandoned lagoons can be difficult and expensive. The trucked system for holding tank wastes is primarily a method of collection and does not involve treatment processes. Sewage and kitchen wastes are piped into a large holding tank which is periodically pumped to a tank truck and removed for disposal. This method of disposal usually involves the discharge of the waste water directly to land. From an environmental and public health standpoint, such a method is undesirable.

This study involves an assessment of the operational characteristics of a washcar-incinerator complex and determining whether such a unit is a feasible alternative to the above methods for the collection and disposal of fecal wastes in northern construction camps. The complex is composed of two mobile trailers; an incinerator, and a washcar which contains two types of vacuum toilets (Vacusan, 2 units and Vacu-Flush, 1 unit) and 2 chemical recirculating toilets (Jet-O-Matic), as well as regular washbasins, urinals, showers, clothes washers, driers and a sauna. (Fig. 1-3).

Feces, from the flush toilets, are drained by vacuum into a holding tank situated in the washcar. When the tank is full the vacuum is released and the contents are pumped via a utilidor into a holding tank in the incinerator trailer where the sewage is macerated then pumped into the incinerator for combustion. The chemical recirculating toilets, when full, are also pumped into the holding tank in the incinerator car. Figure 4 gives the plumbing system for the washcar.

2.2 Specific Objectives

2.2.1 To assess the general performance and user preferences for the 3 types of toilet units and to determine their water conservation capabilities.

2.2.2 To assess the performance of the incinerator in terms of power and fuel requirements, combustion efficiency and stack emissions.

2.2.3 To determine, from the above and other related information, the economic and operational feasibility of this type of unit as a method of waste disposal for northern camps.

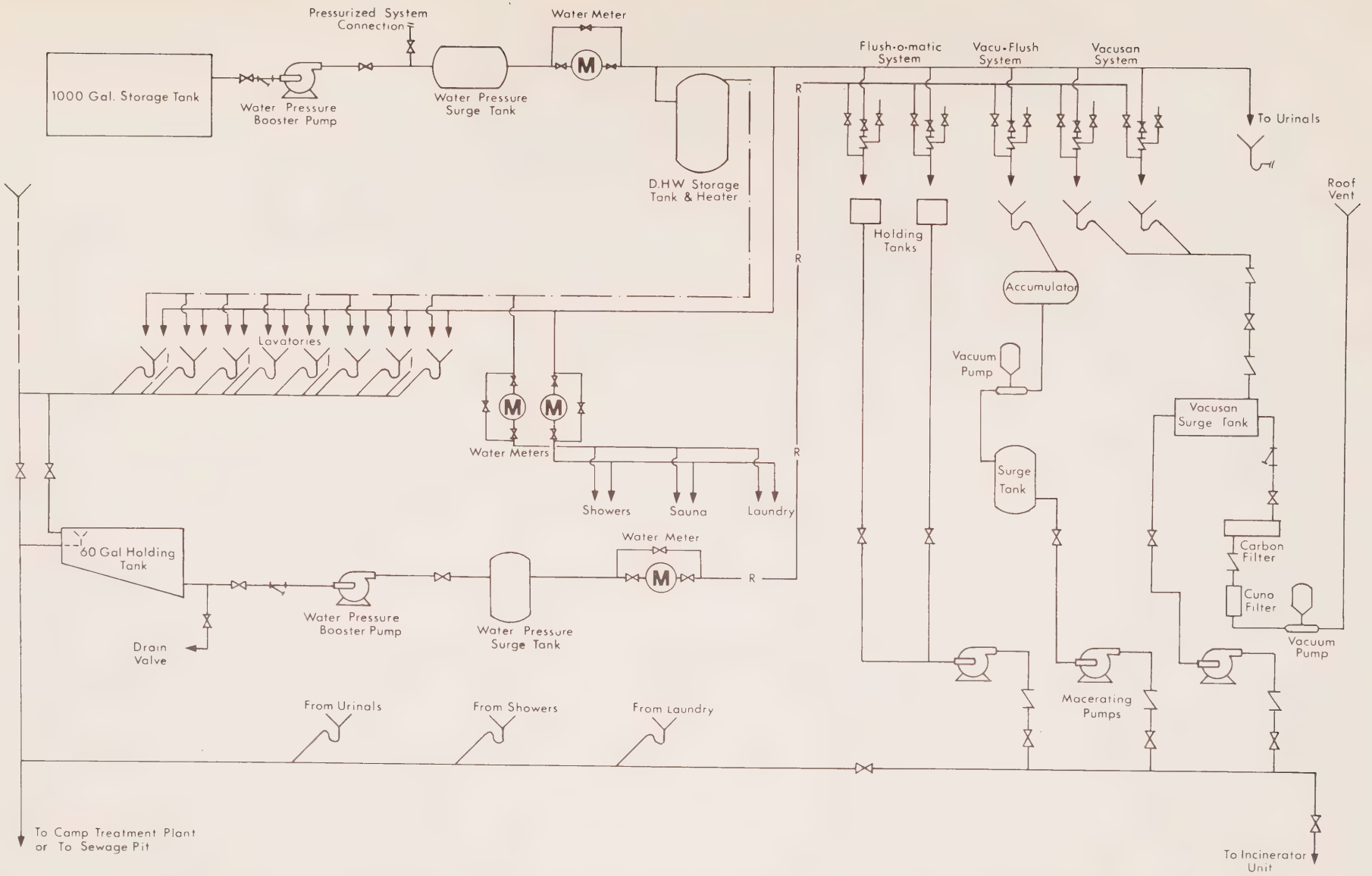
2.3 Relation to proposed pipeline development

If construction of a pipeline through the Mackenzie Valley is undertaken, a proliferation of transient construction camps would be anticipated along the proposed route. It would be beneficial for construction contractors and supervisory personnel to have available rugged sewage collection and disposal systems which are portable, consume minimal amounts of water, and which keep discharges of wastes to the environment at a minimum. The prototype washcar-incinerator complex involved in this study could possibly meet these requirements.

Fig. 1 Interior of washcar, sauna entrance in background

Fig. 3 Feces incinerator furnace

Fig. 2 Exterior of incinerator trailer



PLUMBING SYSTEM FLOWPLAN - FOR WASHCAR FIGURE 4

3. CURRENT STATE OF KNOWLEDGE

The use of vacuum toilets and liquid waste incinerators is still a relatively new field in sanitary engineering. Their viability in northern climates as an alternative to conventional methods of collection and disposal of sewage is still unproven, except in isolated case studies (Averill and Heinke, 1973; Miholits, 1961; Baribo, 1957). This study will provide information gathered on a long-term basis, under actual camp conditions, as to the feasibility of such a disposal method.

4. LOCATION OF STUDY

The washcar trailer and incinerator complex is presently situated at DPW Workcamp #1, Ft. Simpson, N.W.T. It is planned to move the trailers to another, larger workcamp to allow the unit to be observed operating at full capacity and, also, to supply information as to the general mobility of the trailers and requirements for re-installation after transport.

5. METHODS AND SOURCES OF DATA

5.1 Water, Power and Fuel Consumption

Meters were installed to monitor the following:

a) total washcar water consumption

b) shower and laundry water consumption (two meters, hot and cold)

c) urinal and lavatory consumption was calculated from the above i.e. a-b=c

d) vacuum toilet water consumption. Wash water is recycled, through a water meter, from a holding tank below the hand basins to the vacuum toilets.

e) electrical power consumption for both the washcar trailer and the incinerator trailer.

The chemical toilets were charged with a known quantity of water. Fuel oil consumption for heating the washcar trailer and for incinerator fuel was not metered, but consumption rates could be derived from the known fuel tank sizes and records of the volumes purchased.

5.2 Maintenance

Records of repairs and maintenance requirements are kept for all equipment. In particular, these records will be useful for comparing the durability and performance of the two types of vacuum toilets and the chemical recirculating toilets.

5.3 Operator Requirements

From daily observations of the washcar-incinerator operations, a set of recommendations regarding operator duties and responsibilities will be formulated.

5.4 Analysis of User Preferences

Preferences of the workcamp members for the various types and makes of toilet units will be determined quantitatively by the use of flush counters which are installed in the toilet units and which record the number of times each was used. A subjective assessment of the attitudes of the workmen towards the toilet units and the sauna will be made through conversations with the men.

5.5 Incinerator Operation

Operating characteristics of the incinerator unit with regards to furnace temperature, oil feed rate, air supply pressure, efficiency of organics destruction, and stack emissions will be determined.

6. RESULTS

6.1 Water, Power and Fuel Consumption

Table 1 gives the weekly and month end summary of the water consumption and power requirements for the washcar. The total water requirements for the month (28 days) was 51,300 litres or 100 lpcd. The vacuum toilets consumed 940 litres of water through the last 3 weeks of operation, at an average of 1.5 litres/flush. The chemical toilets required less water, 65 litres/charge, each charge lasting 100 flushes, under the present infrequent use. The amount of water used in the chemical toilets for the first month of operation was approximately 157 litres. Thus, the total toilet water consumption for the first month can be estimated to be in the range of 1350 to 1515 litres.

The washcar consumed approximately 80 kwh/day of electrical power, regardless of the camp size. Extended use of the sauna, which is rated at 9 kW, may eventually raise this figure. Fuel consumption of both the washcar and incinerator has not been investigated to date.

6.2 Maintenance

All of the equipment in the washcar was found to perform satisfactorily but daily checks are required to ensure their continued operation. The Vacu-Flush toilet system was initially plugging due to insufficient vacuum but this problem has been rectified.

When sewage is being pumped from the toilet holding tanks to the incinerator car, care must be taken to ensure that the macerating pumps do not run "dry". They must be shut-off immediately upon completion of pumping or pump seizures will develop.

6.3 Operator Requirements

To ensure proper performance of the units, the operator should:

1. Ensure the safety, security, cleanliness and habitability of the units.

2. Maintain adequate supplies of fuel oil and water.

3. Ensure all equipment including pumps, motors, valves, toilets, etc. are operating correctly and effectively.

4. Incinerate sewage when necessary; the operator must pump the stored sewage from the washcar to the incinerator car holding tank thence to the incinerator.

TABLE 1

UTILITIES CONSUMPTION

WEEKLY AND MONTH-END SUMMARY

	Water Consumption (litres)				Elect Power kwh	Camp Attendance
		laundry & showers				
	Meter #1 Total Water	Meter #2 Cold	Meter #3 Hot	Meter #4 Toilet		
Week #1						
Total	15048	6500	4780	650	-	175
Daily Avg.	2149	928	680	93	-	25.0
Week #2						
Total	13815	4666	4585	420	530	152
Daily Avg.	1973	666	655	60	75.7	21.7
Week #3						
Total	3630	5540	4300	300	601	110
Daily Avg.	1947	790	610	43	85.9	15.7
Week #4						
Total	8833	3325	2240	220	556	88
Daily Avg.	1261	475	320	31	79.4	12.6
4 Week Total	51327	20034	15903	1590	1,687☆	525
Weekly Average	12831	5008	3975	400	562.3☆	131.3
Daily Average	1833	715	567	56	80.3☆	18.8

☆ Three weeks used as basis for calculation

☆☆ 30 gal/mo. required to charge the chemical toilets not included in data

5. Ensure all freeze-up prevention equipment including furnaces, heat tape, insulation, etc. are operating effectively.

6.4 User Preference

A summary of the weekly toilet flush counts is given in Table 2. As shown in the table, the vacuum toilets received a much greater usage than the chemical (Jet-O-Matic) recirculating toilets. The vacuum toilets were preferred by the patrons because they most resemble conventional flush toilets. The chemical toilets emit an inoffensive chemical odor and the user must ascend a large step before use. They are slower acting in the flush cycle and comparatively quiet in flush operation, giving the user a feeling that they are under-designed.

The comments made by the washcar patrons included humorous anecodotes about the drawing power of vacuum if the toilet was flushed while the user was seated. Various names such as "Atomic Toilet" have been tagged to the washcar-incinerator complex. The noise emanating from the vacuum toilets greatly exceeds that of standard flush toilets.

6.5 Incinerator Operation

Study has not been completed as yet. Table 3 gives some data on the results of a trial incineration conducted on September 24, 1973.

TABLE 3

INCINERATION - SEPT. 24/73

Time	Inc.[1] Temp (°F)	Waste Liquid[2] Pump Setting (Revolutions)	Air Temp[3] (°F)
10:45 a.m.	-	-	52
11:08	1460	3	58
11:31	1420	8	65
11:40	1400+	13	68
11:50	1380+	17	71
12:00 noon	1360+	17	73
STOP INCINERATION SEQUENCE			
START INCINERATION SEQUENCE			
2:20 p.m.	560	-	70
2:35	1460	3	71
2:53	1440	8	-
2:56	1420+	13	76
3:06	1400+	17	78
3:56	1460	24	89
4:16	1400+	28	91
4:25	1400+	28	91
4:31	1400+	28	92
4:41	1400+	28	92
4:52	1410+	28	93
5:00	1410	28	94
5:01	1410	28	-
5:05	1200	-	95
5:08	1500	-	95
5:10	1440	28	96
5:15	1420	28	95
5:25	1420+	28	95
5:30	1440	28	94
5:32	1440	28	94

(1) Temperature inside incinerator.
(2) Worm gear revolutions

0 rev. setting = no flow rate
28 rev. setting = max. flow rate at max. gear setting (approx. 135 gal./hr.)

(3) Temp. within incinerator trailer, close to power supply panel.

Notes

10:45 a.m. - 12:00 Waste water incineration rate 54 imp gal/hr
4:31 - 5:00 p.m. " " " " 130 " " "
5:08 - 5:32 p.m. " " " " 144 " " "

TABLE 2

WEEKLY TOILET FLUSH COUNTS

Toilet	Week #1	Week #2	Week #3	Week #4	Total 4 Weeks
#1 Vacusan	103	106	94	84	387
#2 Vacusan	106	79	57	34	276
#3 Vacu-Flush	not recorded	87	34	30	151
#4 Jet-O-Matic	42	35	25	19	121
#5 Jet-O-Matic	flush counter removed		-	-	-
Camp attendance (man days)	25.0	21.7	15.7	12.6	18.8

Note: - The term "man days" refers to the average daily camp attendance for each seven-day period.

- The flush counter installed on toilet #5 was removed after the first week, and relocated on toilet #3. Toilet #5 was getting very little use and toilet #3 was installed by the manufacturer without a flush counter.

7. DISCUSSION

Average water consumption in construction camps has been rated by Fair et al (1966) at 45 lpcd (U.S.), but this includes kitchen consumption, drinking water, etc. A breakdown, by the above authors, of domestic (urban) water consumption apportions the uses as follows:

a) 41% to flushing toilets
b) 37% to washing and bathing
c) 6% to kitchen use
d) 5% to drinking
e) 4% to washing clothes
f) 3% to household cleaning
g) 4% to miscellaneous activities

Thus, the washcar requires approximately 85% of the total camp water. Based on the above construction camp rating, the washcar patrons, using conventional flush toilets would consume

143 lpcd. (45 US galls x .85 x 3.8)= 143

The following calculations give two separate estimates of the volume of water saved during the first month of operation:

I. (143 - 98) litres x 28 days x 18.8 man days

= 23790 litres

II. 1156* flushes x 22.5 litres/flush (conventional toilets)

= 2600 litres

From the above calculations it can be assumed that the washcar installed toilets saved the camp in excess of 21,100 litres for the period under study. Much greater savings would be realized with a larger camp size. Discussion of the other aspects of this study, as well as further comment on water consumption, will be dealt with at a later date when more data are available.

*Note: The first week flush count for the Vacu-flush toilet was estimated to be similar to the Vacusan units (approx. 100). Usage of the #5 Jet-O-Matic toilet was assumed to be the same as the #4 toilet.

8. RECOMMENDATIONS

Although toilet water consumption has been reduced, further attempts should be made to further curtail the overall water usage. This could possibly be achieved through the use of shower water timers and washing machines with low water requirements. Meters to measure kitchen and laundry water use should be installed to provide further information on total consumption.

At capacity, the washcar is designed to handle 40 patrons. With an average daily consumption of approximately 90 litres/person the 4500 litre holding tank is underdesigned. At present, the operator has difficulty maintaining adequate water supplies, especially over holiday and week-end periods of maximum usage. The future water storage capacity for washcar trailers maintaining camp sizes of this nature should be in excess of 9000 litres.

Future designs should possibly consider a third trailer which would contain:

1. Electrical generator
2. Large volume water storage
3. Fuel oil storage
4. Spare parts and supplies

Such a unit should be portable and connectable to the other units.

9. REFERENCES

Averill, D.W., and G. W. Heinke, 1973, Vacuum Sewer Systems, Dept. of Civil Engineering, University of Toronto.

Baribo, L.E., 1957, Field Testing of Ground Type Incinerator Toilets under Arctic Conditions, Tech. Note AAL-TN-57-6, USAF, Arctic Aeromedical Lab.

Fair, G.M., J.C. Geyer, and D.A. Okun, 1966, Water and Wastewater Engineering, Vol. 1, John Wiley and Sons Inc., New York.

Miholits, E.M., 1961, Research and Development of a New Method of Waste Disposal for Isolated Sites in the Arctic, Tech. Rep. 61-9, USAF, Arctic Aeromedical Lab.

THERMAL EXPANSION COMPENSATION IN ABOVE GROUND WATER PIPING SYSTEMS FOR LOW TEMPERATURE ENVIRONMENTS

by

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under contract to:

Technical Branch
Environmental Protection Service
Northwest Region
Environment Canada

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1. SUMMARY

Because of the significant number of unexplained expansion joint failures in situations where these joints are subjected to freezing water, an investigation of the behaviour of various types and makes of expansion joints was done in the laboratory. As many of the reported failures have occurred in water lines after they had been drained, the study concerned itself with joints which were frozen with only a small amount of water remaining in them.

Four different steel piping expansion joints were treated under freeze-thaw conditions simulated in low temperature environmental chambers. Neither of the two slip-type joints proved to be satisfactory. The packed-slip joint was not suitable due to excessive maintenance and alignment requirements. The Dresser coupling became too stiff at low temperatures and would probably cause buckling of the pipe under certain conditions. Of the other two joints tested, the internally-supported bellows proved unsatisfactory as ice tended to be trapped and hindered the normal operation. The free-flexing bellows was the best of the types tested. With ice frozen inside it, the joint performed adequately provided the amount of contraction was limited to 50% of its rated amount.

While the joints tested in this study were for 2 and 3 inch diameter lines, it is believed that the results would be applicable to other, larger sizes of water piping joints.

2. INTRODUCTION

If development of a proposed Mackenzie Valley gas pipline is undertaken, a large number of construction camps will be necessary. Life-support systems, including sewage and water distribution, will be a requirement for any camps located along the proposed route. The failure of expansion joints in water and sewage lines, due to the severe freeze-thaw conditions experienced in Canada's north, have been previously encountered. It was therefore proposed to study the behaviour of a number of types of expansion joints used in steel piping systems under low temperature (sub-freezing) conditions. In particular their ability to expand and contract both with and without water frozen inside them was to be investigated in the laboratory. The primary objective was to find expansion joints which will perform satisfactorily in northern climates.

3. CURRENT STATE OF KNOWLEDGE

Normally the temperature in the piping of an above ground water distribution system is maintained at a relatively constant value equal to that of the water circulating in it (approximately 40°F). However such systems may occasionally have to be shut down and the lines drained in which case the pipe may be subjected to the full range of air temperatures. This temperature range may be as large as 160°F. For steel pipe this range of temperature would produce approximately 1-1/4" of length change per 100' of pipe.

The three common techniques available for absorbing this length change are:

(1) a "snaked" or "zig-zag" line
(2) expansion loops
(3) an "in-line" expansion joint.

Each has specific advantages and limitations.

The "snaked" or "zig-zag" line has perhaps some advantages as far as simplicity is concerned. It does, however, require more lateral space than the "in-line" expansion joint. For example with anchor points at 100' intervals a "snaked" line would have to be offset some 3' from a straight line. This means that the "snaked line" cannot be used in a utilidor although it may be acceptable when laying pipe over an open area. Less lateral offset is required if the anchor points are more closely spaced. For example with anchor points every 20' the offset is only half a foot. The radius of curvature of the pipe bends between anchor points however, is too small for the large diameter pipes.

Expansion loops may be built into the line, however these tend to be expensive to install as well as substantially increasing the pressure drop in the line. The Federal Department of Public Works has tried a rather simple expansion loop constructed with ball and socket joints. These joints however failed under low temperature conditions.

The most feasible type of expansion device for a utilidor would be an "in-line" type of joint. The normal procedure of designing for expansion and contraction using this type of joint is given by Wilbur (1967). The types of "in-line" joints tested were:

(1) Dresser type coupling
(2) Packed-slip type
(3) Internally-supported bellows
(4) Free-flexing bellows

Sketches of these joints are shown in Figures 1 through 4.

The Dresser type coupling is not designed as an expansion joint; however, it will take about 1/4" of movement under normal conditions. Thus if they are spaced at 20' intervals they normally will suffice as expansion compensators.

The packed slip type is a much more sophisticated expansion compensator designed primarily for industrial plant use. A single unit can accomodate the large expansions, up to 12", that occur in high temperature lines. They have the disadvantages that they require routine maintenance and accurate alignment of the pipes to be joined.

The internally-supported bellows and the free-flexing bellows both employ a corrugated metal bellows to compensate for the expansion. They differ in the way the bellows are physically arranged in the joint as shown in Figures 3 and 4.

Operation experience with in-line type expansion joints has shown that failures frequently occur if the pipe must be shut-down and drained during the winter. The Federal Department of Public Works has experienced some failures of an internally-supported bellows joints (a type of which was tested in this study). Environment Canada's Technical Branch, Edmonton, also reports that "Dresser" type couplings, which at normal operating temperatures provide for some expansion and contraction, fail to do so under freezing conditions (Grainge, Pers. Comm.)*. From these observations it was surmised that the expansion joints were failing because either the joints were becoming stiffer at the cold temperatures or ice formed from the water left in the joint was preventing the normal operation of the expansion joint. These conditions were simulated in the laboratory.

*Grainge, J.W., Senior Project Engineer, Technology Program, Environmental Protection Service, Edmonton, Alberta.

METHODS

Four different types of "in-line" expansion joints were tested. These are the Dresser coupling, packed-slip type, internally-supported bellows and free-flexing bellows. The particular joints tested and approximate prices are listed in Table I.

In the first series of tests the joints indicated in 1, 2, 3 and 4(b) of Table I were subjected to six different tests each. In all these tests the joints were expanded or contracted in a hydraulic testing machine with the objective of determining what force would be required to produce a deformation in the joint of 0.25".

The six tests on each joint consisted of three tension and three compression tests. These tension and compression tests were conducted at room temperature (70^{o}), at -20^{o}F and at -20^{o}F with water frozen inside the joint. In this last test with the joint and connecting pipes in the horizontal position, water was put into the joint until it began running out of the ends of the pipe. The water was then frozen and the entire assembly transferred to the environmental chamber in the testing machine, cooled to -20^{o}F and tested in tension. After the tension test the ice was melted and refrozen before the compression test was started.

A further sequence of tests were conducted to determine the effects of larger amounts of ice in the joints, as well as greater deformations of each joint. These tests were concentrated on the packed-slip and free-flexing type of joint since the first series of tests had shown them to be superior to the others.

Finally a series of tests were done on free-flexing joints of different lengths (numbers 4(a) and 4(c) Table I). These tests were designed to determine the maximum compression that the free-flexing joints with ice in them could take without suffering permanent deformations.

TABLE I

Type of Joint	Price (f.o.b. Edmonton)
1. Dresser Coupling, 2" nominal pipe.	$ 13.00
2. Packed-slip expansion joint 2" nominal pipe.	224.00
3. Internally supported bellows, 2" nominal pipe.	69.00
4. Free-flexing expansion joint 3" nominal pipe	
(a) one with 4 corrugations	144.00
(b) one with 6 corrugations	159.00
(c) one with 8 corrugations	175.00

5. RESULTS

The results for the first series of tests were summarized in Table II. Shown are the loads required for a 0.25 inch compression or expansion of the joint. In some instances the load reached a maximum value before a 0.25 inch displacement was obtained and then the load fell off with further displacement. In these cases the maximum load is recorded.

The free-flexing bellows were observed to suffer permanent deformation if they were compressed excessively with ice trapped in the bellows. For example, Figure 7 shows the result of compressing the six corrugation, free-flexing bellows joint one inch. Several sizes of joints were tested to determine the maximum compression that could be tolerated without permanent deformation. These results along with the specified maximum axial traverse are shown in Table III. It will be observed that the maximum safe traverse with ice frozen in the bellows is about 50% of the normally specified traverse.

TABLE II

Forces Required to Displace Various Expansion Joints 0.25" under Normal and Freezing Conditions

	Tension (lb)			Compression		
	Room Temp.	-20°F	-20°F with Ice	Temp.	-20°F	-20°F with Ice
1. Dresser Coupling 2" nominal pipe	2100*	5000*	6350*	3700	6100	9700
2. Packed-slip type 2" nominal pipe	400*	900*	600*	500*	380*	2700*
3. Free-flexing bellows 3" nominal pipe	125	125	125	125	125	150
4. Internally-supported bellows 2" nominal pipe	100	100	2400	70	120	3600*

* maximum force occurred before a displacement of 0.25" was reached

TABLE III

Maximum Joints Traverse of
Free-Flexing Bellows

No. of Corrugations on Joint	Specified Maximum Axial Traverse	Maximum Safe Traverse with Ice Frozen in Bellows	% of Specified Traverse
4	1"	1/2"	50
6	1-1/2"	3/4"	50
8	2"	1"	50

TABLE IV

Free-Flexing
Expansion Joint Costs

	No. of Corrugations	Quoted Price f.o.b. (Edmonton)	Allowable Traverse (inch)	Required Joint Spacing (ft.)	Cost per foot f.o.b. (Edmonton)
3" nominal pipe	4	$144	0.5	40	$3.60/ft
	6	159	0.75	60	2.65/ft
	8	175	1.0	80	2.19/ft
	10	190	1.25	100	1.90/ft
6" nominal pipe	6	248	1.12	90	2.75/ft
	8	271	1.5	120	2.25/ft
	10	294	1.88	150	1.96/ft

6. DISCUSSION AND CONCLUSIONS

Of particular interest in the results is the change in the force required to operate the joints that occurs when they are cold and when they have ice in them. Also of interest is the maximum force required for compression of the joint. For the two-and three-inch diameter joints tested it is estimated that the pipe between supports spaced 20 feet apart would buckle if the force in the pipe exceeds three or four thousand pounds. This will happen instead of the joint compressing.

The force required to operate the "Dresser" coupling, which was high at room temperatures, increased to 5000 or 6000 pounds when the joint was cooled to -20°F without any ice in it. The force increased even further when ice was frozen in it. It is therefore probable that such a joint would provide no expansion compensation under freezing conditions.

The internally-supported bellows, which required forces of about 100 pounds at room temperature and at -20°F, required forces of the order of 3000 pounds when ice was frozen in them. These high forces were due to the design of the bellows structure (Figure 3) which traps the ice formed. This is primarily why internally-supported bellows joints have failed during a shut-down cycle.

The forces required to operate the two remaining joints, the packed-slip type and the free-flexing bellows, were acceptable, the free-flexing bellows showing the least adverse effect from having ice frozen in it.

If the amount of ice frozen in the joint was increased the force required increased considerably. For example for the packed-slip type half full of ice the force required was 5000 pounds whereas with a very small amount of ice in it the force was 2700 pounds. One could conclude that any piping system must be designed so that the expansion joints will drain to the greatest extent possible.

In tests where the amount of compression was increased from 0.25 inches to one inch it was found that the maximum force required for the packed-slip type was 3400 pounds while that for the free-flexing bellows was 1000 pounds. (The specified maximum expansion for these joints are 4" and 1-1/2" respectively.) The higher force required for the packed-slip joints, along with the fact that they require maintenance and accurate alignment, would tend to rule them out for expansion compensation under freezing conditions. This leaves the free-flexing bellows as the most acceptable expansion joint from a technical point of view.

7. RECOMMENDATIONS

7.1 Type of installation recommended.

It is recommended, that in future installations of above-ground water piping systems, the free-flexing bellows joint be tried. A record of its performance as well as that of other types of joints should be kept in order to relate the field experience to the findings of this study.

7.2 Method of installation and cost.

Installation and Cost of the Bellows Expansion Joints

For installation of bellows joints, it is essential that the manufacturer's specifications be followed. For proper behaviour of the joints it is of particular importance that the proper pipe anchors, pipe guides, and expansion joint pre-compression are used in the piping installation. We would recommend that for the case where ice may become frozen in the bellows the maximum axial traverse should be only 50% of the specified maximum for a given type of joint.

The costs of a number of sizes of free-flexing expansion joint as quoted in December 1973 are listed in Table IV. Also shown in Table IV are the allowable expansion for each joint (one half of the specified value), the required expansion joint spacing and the cost per foot this would add to the pipe. Note that this last column does not include the cost of pipe anchors, pipe guides, and associated installation costs.

In each case the most economical joints are the ones that take the most displacement per joint; that is, the one with the largest number of corrugations. The minimum cost for both the 3" and 6" pipe sizes, using ten corrugation joints, is around $2 per foot of pipe.

It should be remembered that the free-flexing bellows with 10 corrugations will not have very much lateral stiffness and the proper installation of alignment guides is particularly critical.

8. NEEDS FOR FURTHER STUDY.

No further requirements for the study of expansion joints are anticipated at this time.

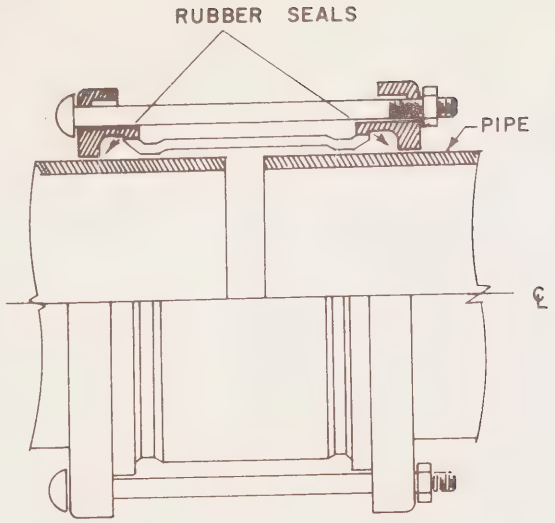

FIGURE 1 DRESSER COUPLING

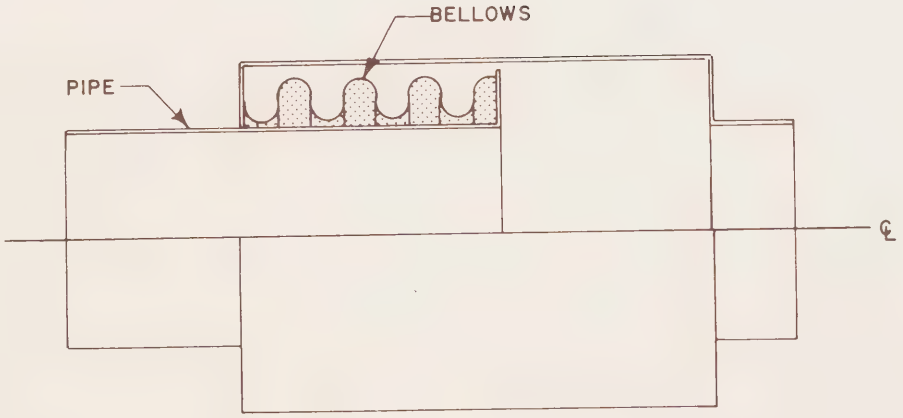

FIGURE 3 INTERNALLY-SUPPORTED BELLOWS

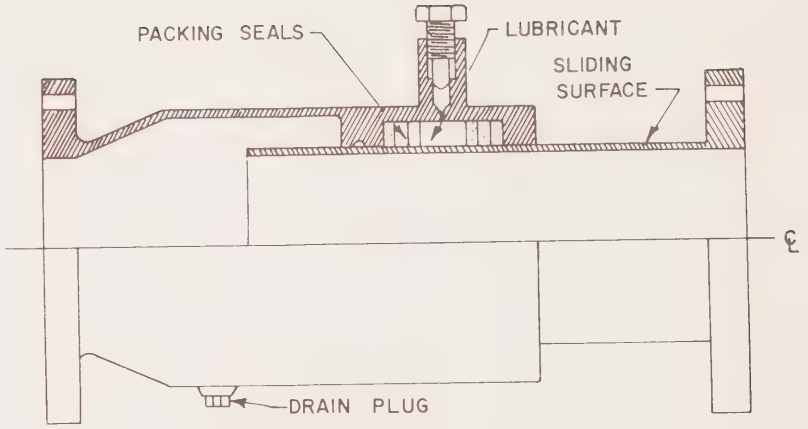

FIGURE 2 PACKED-SLIP TYPE

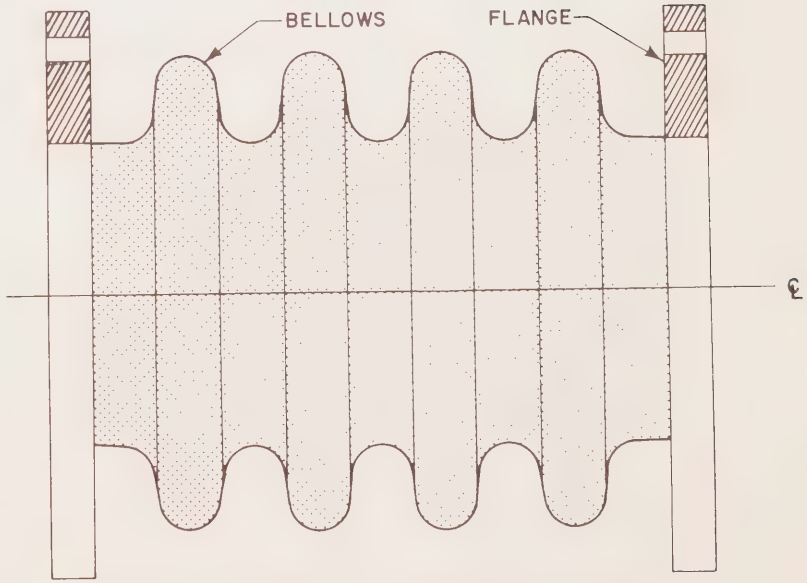

FIGURE 4 FREE-FLEXING BELLOWS

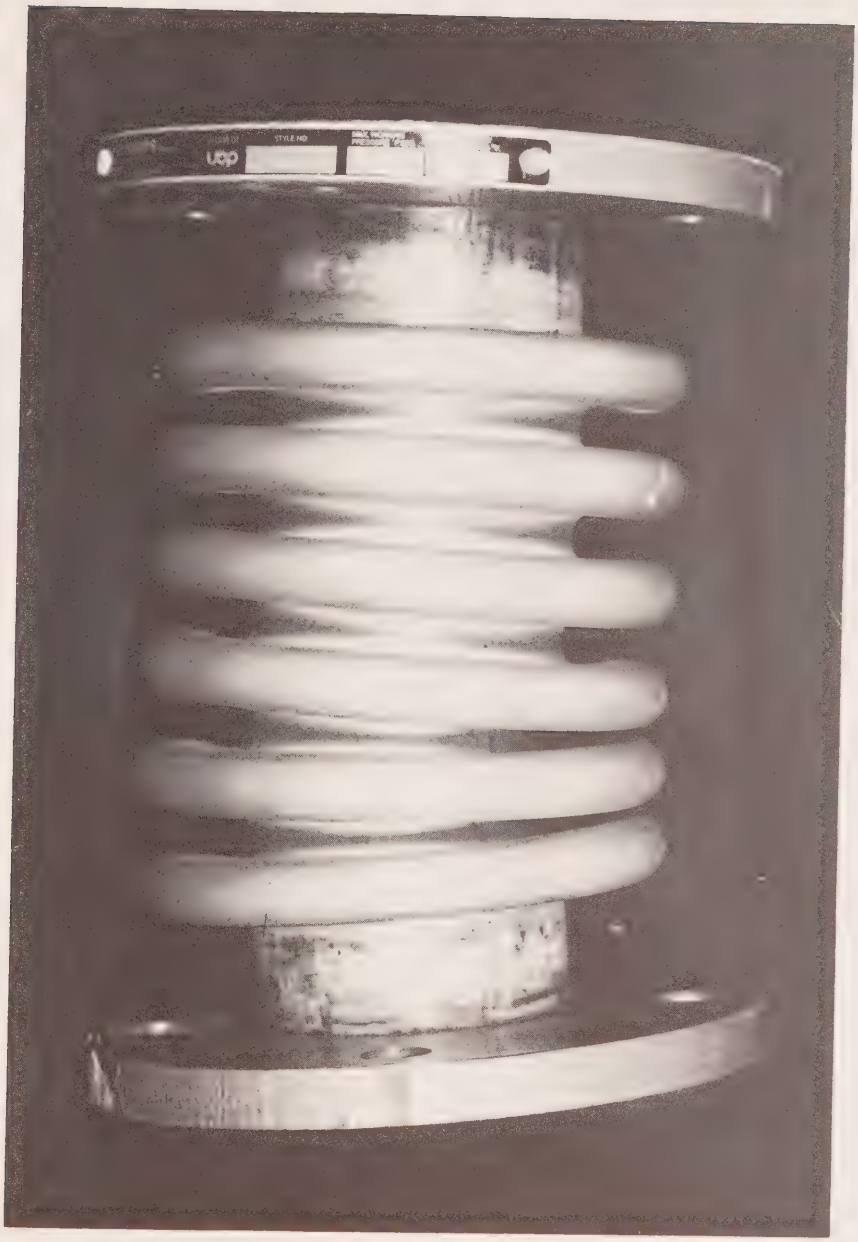

Figure 5 Permanent Deformation due to Over Compression of a Free-Flexing Bellows Joint

9. REFERENCE

Wilbur, E.R. 1967. Handling Expansion and Contraction in Piping Systems. Dom. Eng. Vol. 210, No. 5. pp. 50-53 and 70-74.

EFFLUENT CRITERIA

THE FATE OF ALGAE IN ALGAE-RICH EFFLUENTS

by

R. EDWARDS

Technology Programs

Technical Branch
Environmental Protection Service
Northwest Region
Environment Canada

March 1974

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* Available on application to Manager, A.L.U.R. Program, Northern Natural Resources and Environment Branch, Department of Indian and Northern Affairs, Ottawa, Ontario. K1A 0H4

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1. SUMMARY

Sewage oxidation ponds will probably be used by construction camps in northern areas to treat their wastewater. The treated effluent from these oxidation ponds could be discharged to small streams and water bodies.

During the summer months, algae (phytoplankton) in the oxidation ponds multiply rapidly and reach high concentrations. These algae are carried in the effluent and are continually discharged from the oxidation pond into the receiving water during the summer. Since the physical and chemical quality of the receiving water is vastly different from that of the effluent, the algae are suddenly placed in a different environment which will affect their physiological activity. It was thought that the change of environment might be sufficiently severe to cause a downstream die-off of the effluent-borne algae.

Studies of two oxidation ponds and their respective receiving waters in Alberta have indicated that although high levels of algae, principally *Scenedesmus quadricauda*, *S. falcata* and *Actinastrum* spp. are discharged to receiving waters, they remain alive and in apparent good condition for considerable distances downstream of their release point. Since they remained alive, they did not impose an oxygen demand on the receiving water and did not reduce dissolved oxygen levels. It therefore appears that, in respect of oxygen demand, effluent-borne algae do not have a deleterious effect on a receiving water during the summer.

2. INTRODUCTION

The Mackenzie Valley Corridor has been suggested as a possible route through which the significant finds of natural gas in the western arctic may be brought to southern markets. The construction of a pipeline to transport this gas could take several years to accomplish and will require the development of a large number of construction camps.

Construction camps will generage large quantities of wastewater which must be treated to an acceptable level before it is discharged to the environment. The use of sewage oxidation ponds has been suggested (Grainge et al, 1973) as a suitable method of wastewater treatment for these construction camps.

In an oxidation pond, degradation of organic material takes place through bacterial oxidation which releases carbon dioxide to the wastewater. During the summer, algae in the oxidation pond reuse the carbon dioxide to form algal biomass. By this means a large concentration of algae can develop in an oxidation pond by the end of the summer. The effluent which is discharged from an oxidation pond will therefore contain large numbers of algae. Under certain circumstances, the effluent-borne algae, which have developed in the warm and nutrient-rich waters of an oxidation pond, may be discharged to a cold and oligotrophic receiving water. Discharged algae can be expected to affect the downstream receiving waters in various ways.

If the algae are unable to survive in their new environment a sudden die-off would impose a heavy oxygen demand on the receiving water, resulting in decreased levels of dissolved oxygen. Alternatively, the algae may remain alive, but their growth rate would fall to a low level. In this case, they would not exert an oxygen demand on the receiving water.

The project was divided into two phases, the first being to determine the fate of algae released from oxidation ponds and the second to develop alternative tests for algae-rich effluents which will accurately assess the efficiency of oxidation pond treatment of effluents. The first phase of this study is reported here.

3. CURRENT STATE OF KNOWLEDGE

Sewage oxidation ponds serving settlements in arctic and sub-arctic areas have been in existence for some time. The oxidation pond at Inuvik, for example, which was built in 1959, has been extensively studied by Dawson et al, (1973), who reported that the oxidation pond produced an 85% reduction in BOD_5 from the raw sewage to effluent in summer and 41% reduction in winter.

The effects of sewage effluent on receiving water quality in Banff National Park have been studied by Robinson (1972) and by Krishnaswami and Slupsky (1970). They concentrated on water chemistry, invertebrate communities and phytoplankton, but did not consider in depth, the algal fraction of the oxidation pond effluent and its fate in the receiving water.

Oxidation ponds produce high concentration of algae during the summer and the fact that there is little information on the fate of algae discharged into receiving waters has been pointed out by Caldwell and Parker (1973). These workers suggest that under certain conditions, discharged algae can constitute a BOD_5 load on the receiving water and decrease the dissolved oxygen level. This is only likely to occur if the algae are discharged to an environment unfavourable for their maintenance or growth and they decay.

The standard tests which are applied to determine the efficiency of an oxidation pond or wastewater treatment plant include the determination of biochemical oxygen demand (BOD_5) and suspended solids (SS). In the BOD_5 test, a sample of water or effluent of known oxygen level is incubated for 5 days in the dark at 20°C after which the oxygen level is again determined. The difference between the initial and final oxygen concentration is calculated in terms of oxygen utilized per litre of wastewater over the test period. If the test water contains significant quantities of algae, then, under 5 days of continuous dark conditions, these algae will respire and use their stored food products, and in so doing they will utilize dissolved oxygen from the water. Conversely, if the test were run under well-lighted conditions, the algae would be producing oxygen through the process of photosynthesis and consequently the oxygen level in the water would rise. In fact, tests have demonstrated that when BOD_5 bottles containing an algae-rich effluent are submerged in a receiving stream under natural conditions, the level of dissolved oxygen in the bottles increases, indicating a negative BOD_5 whereas running the test in the dark indicates a high BOD_5.

The BOD_5 test is intended to indicate the amount of oxygen required to oxidize organic material in the water sample through bacterial action. Living algae cells will not be

decomposed by bacteria under natural conditions. It is only when the algae cells have died that they can be decomposed by bacteria and an oxygen demand on the water is exerted. The BOD_5 test, therefore, is unsuitable for algae-rich effluents.

The suspended solids consist of organic and inorganic material which is held in suspension in the water. The algae fraction constitutes suspended solids and is included in the test result. A high concentration of algae in the effluent will result in a high SS reading.

There is a fundamental difference between the processes involved in the operation of an oxidation pond and those involved in the operation of an activated sludge plant for example.

In an oxidation pond, non-living organic material which enters the pond in the influent is broken down and oxidized by bacterial action. This oxidation process releases energy, which the bacteria utilize for growth and metabolism, and carbon dioxide, which is released into the surrounding water, and may escape into the atmosphere. The bacteria, therefore, require oxygen to degrade the organic material and this oxygen is supplied to some extent by gas exchange at the air-water interface, but mostly by algal photo-synthesis. In the process of photosynthesis, algal cells remove carbon dioxide from the water and build it into algal biomass, using the energy from sunlight to do so. To summarize, most of the organic material in the influent is oxidized to carbon dioxide by bacterial action, but much of the carbon dioxide is reconverted into organic material as algal biomass. The net result therefore, in general terms, is that the non-living organic matter entering the pond is converted into living organic matter and comparatively little carbon is lost from the system.

In an activated sludge treatment plant, bacteria break down the incoming organic material, but the oxygen they use in this process is provided by forced aeration of the waste-water. The carbon dioxide generated through bacterial action is partly lost to the atmosphere and is partly lost by being carried out of the plant in the effluent. By this process, much of the organic material entering the plant is converted into carbon dioxide. The bacterial biomass which is synthesized within the plant is settled out and returned to the influent line, thus producing an effluent of good quality.

Since the biological processes which take place in enclosed mechanical treatment plants and oxidation ponds are very different, it is unreasonable to apply the same measuring

stick to both types to determine their efficiency. Obviously, an algal-laden effluent will always show a high BOD_5 when tested under dark conditions. If it were tested under well-lighted conditions, a negative BOD_5 could well be indicated. Generally speaking, algal productivity is directly proportional to light intensity. Under high light conditions, productivity will be high because the production of biomass by photosynthesis is greater than the breakdown of biomass due to respiration. As light intensity falls, the photosynthetic production of biomass decreases until at a certain light intensity, the photosynthetic production of biomass is approximately equivalent to the breakdown of biomass through respiration. At this light intensity, there will be neither a net gain nor a net loss of algal biomass. If a BOD_5 test were run under light conditions such that there were no change in algal biomass, then, within limits, a reduction of oxygen level in the BOD bottles would be caused by bacterial respiration and oxidation of non-living organic materials.

It has been suggested that the algal fraction of a wastewater sample may be removed by filtration and a BOD_5 test on the filtrate will give a better indication of the quality of the effluent. However, it should be noted that some of the non-living organic material in the effluent is in suspension and will therefore be removed by filtration, along with the algae and some of the bacteria. A BOD_5 test on this filtrate will give an indication of the amount of dissolved organic material in solution. A filtered test is therefore of limited value and is therefore not recognized as a Standard Method.

4. STUDY AREA

4.1 Location of Study

To fulfil the objectives of the study, it was necessary to select a stream which would allow the recovery of algae discharged from an oxidation pond. The receiving water should therefore be a relatively small, flowing stream readily accessible for some distance downstream from the effluent discharge point. There are a number of sewage oxidation ponds in the Mackenzie Valley Corridor, but these were considered unsuitable for field investigation since they discharge into the vast Mackenzie River where any discharged material would quickly become diluted to the point that it was unrecoverable. An ideal receiving water is one where rapid mixing of the effluent with receiving water takes place so that errors in downstream sampling will not arise through poor mixing of the effluent and the receiving water.

These constraints coupled with the necessity for such logistic support as laboratory facilities resulted in the selection of two sites in Alberta.

The two selected sites were Louise Creek, Banff National Park, which receives effluent from a sewage oxidation pond serving Upper Lake Louise, and Battle River, Ponoka which receives effluent from an oxidation pond complex which serves the town of Ponoka. Emphasis was placed on the Louise Creek study.

The oxidation pond serving Upper Lake Louise is a single cell measuring 145 m by 80 m. At a working depth of 1.5 m, it has an estimated surface area of 10,200 m^2 and an estimated volume of 14,200 m^3. At an average flowrate of 0.01 $m^3 s^{-1}$, this oxidation pond will have an estimated retention time of 15 days, which is reduced to 5.8 days at the peak flow of 0.03 $m^3 s^{-1}$.

The lagoon complex at Ponoka consists of 4 anaerobic cells, each of 2100 m^3 capacity at 3 m depth, one intermediate lagoon of 3,000 m^3 capacity at 2.4 m depth, and an aerobic lagoon of 50,000 m^2 extent with a capacity of 93,000 m^3 at 1.8 m depth. The lagoon complex is believed to have been built in 1960 and total containment is practised during the winter months.

The streams chosen for study are very different in character. Louise Creek is a small turbulent to torrential mountain stream (Fig. 1) which drains a glacial melt lake. The creek runs for approximately 3000 m before joining the Bow River. The effluent from the oxidation pond enters the creek approximately 1,100 m downstream from the creek origin.

Figure 1. Louise Creek, midway between sample points B and C.

Figure 2. The effluent outfall which flows into Louise Creek, sample point B.

The water of Louise Creek is consequently cold and oligotrophic. Conversely, the Battle River at Ponoka is a slow-flowing, meandering stream which is passing through an agricultural area. It originates from a small lake approximately 50 km upstream from Ponoka and it eventually joins the North Saskatchewan River in Saskatchewan. It is relatively high in nutrients which are derived from run-off from agricultural land and from seepage from feed lots and farm yards along its course.

4.2 Sample Collection Points

Four sample collection points, designated A,B,C & D were selected along Louise Creek. The location of these points is given below.

Sample Point	Location on Louise Creek
A	Approximately 12 m upstream from the effluent outfall.
B	Outfall of the effluent from the lagoon pipe (Fig. 2).
C	Approximately 1,100 m downstream from the effluent outfall, at the lower road crossing of the creek.
D	Just upstream of the confluence with the Bow River, approximately 1,800 m downstream from the effluent outfall.

On the Battle River, six points were initially selected for sampling, with two additional points selected at a later stage. The location of these points is given below.

Sample Point	Location on Battle River at Ponoka
A	90 m upstream from the effluent outfall.
B	The effluent outfall.
C	60 m downstream from the effluent outfall.
D	230 m downstream from the effluent outfall.
E	800 m downstream from the effluent outfall.
F	1,600 m downstream from the effluent outfall.
G	3,200 m downstream from the effluent outfall.
H	6,400 m downstream from the effluent outfall.

Field investigations were carried out at 2-3 week intervals from 25th June 1973 until 21st September 1973 in both study areas.

5. METHODS AND SOURCES OF DATA

5.1 Flow Measurements

Water flow in Louise Creek was measured where the creek flows through a culvert at the lower exit from the Upper Lake Louise parking lot. The culvert is elliptical and measures 2.4 m wide by 1.8 m high. The depth of water in the culvert was taken and the velocity of the flow through was measured with a Gurley flow meter. The flow could then be calculated. The outflow from the Louise Creek oxidation pond was measured by constructing a small channel along which the effluent flowed. The depth of effluent in the channel and the channel width were noted and the effluent velocity was measured.

The Gurley flow meter was also used to determine the velocity of the effluent leaving the Ponoka lagoon by placing it inside the 25 cm diameter outflow pipe. The depth of effluent in the pipe was noted at the time the flow measurements were taken.

The depth of water in the Battle River prevented measurements of flow rate from being made in early summer. As the flow dropped in late summer, measurements were made at a point where the river flows over a concrete ford. Here, the flow was measured and the cross-sectional area of the stream was estimated.

5.2 Phytoplankton Collection, Preservation and Analysis

Samples of phytoplankton were collected from each of the sampling points. The samples were kept cool during transportation. The samples from Louise Creek were taken to the Canadian Wildlife Service Field Laboratory, Banff, where they were concentrated according to Welch's (1948) method. Formalin was added as a preservative at 5% final concentration.

Due to the abundance of phytoplankton in the effluent samples, these were not concentrated. Formalin was added at the same concentration.

Samples from the Battle River were taken to the Environmental Protection Service Chemical Laboratory, Edmonton, where they were concentrated and preserved in the same manner as those from Louise Creek.

Samples collected during the early summer were counted using a Sedgwick-Rafter counting cell on a compound microscope fitted with a Whipple ocular micrometer, (Welch, 1948). Later samples were counted by sedimenting 1 ml or 2 ml aliquots and using an inverted compound microscope.

Test samples counted by both methods gave comparable results. The drop method outlined by Edmondson (1969) was also tried and found to give comparable results, but it was not used significantly in this study.

Identification of phytoplankton was done with the aid of taxonomic keys (Smith,1950; Prescott,1970; and Ward and Whipple,1959). Only abundant species were identified and counted, since those species which occurred in low numbers could be expected to have little effect on the receiving waters. Counts were of organisms/ml, each coenobium was counted as unity.

5.3 Bacteriological Sample Collection

Standard bacteriological bottles containing a small amount of sodium thiosulphate were provided by the Provincial Public Health Laboratory, Edmonton. These were used to collect water samples for bacteriological analysis and were delivered to the Provincial Public Health Laboratory for analysis on the day of collection.

5.4 Water Quality, Chemical and Physical Parameters

At the time of collection of the phytoplankton samples, measurements of dissolved oxygen and temperature were made with a YSI portable oxygen meter. 4.5 l samples of water and effluent were collected from selected sampling locations and delivered to the Environmental Protection Service Chemical Laboratory, Edmonton, for analysis by the "Standard Methods". Measurements of the total chlorine in the effluent from the Louise Creek oxidation pond were made using the orthotolidine method provided by a Hach DR/2 Field Test Kit.

6. RESULTS

6.1 Flow Measurements

The estimates of flow for Louise Creek and for the two oxidation pond effluents are given in Table 1.

Table 1. Flow Data

DATE	LOUISE CREEK AREA			PONOKA AREA	
1973	Louise Creek A	Oxidation Pond B	Dilution Ratio $\frac{A}{B}$	Battle River	Oxidation Pond
25-26 June	3.7 m^3s^{-1}	0.012 m^3s^{-1}	314	-	-
9-10 July	1.61	0.028	57	-	0.024 m^3s^{-1}
23-24 July	2.46	0.013	189	-	-
13-14 Aug.	2.77	0.007	396	-	0.010
28-30 Aug.	1.33	0.005	266	2.83 m^3s^{-1}	0.014
10-12 Sept.	1.70	0.006	283	0.35	0.014
21 Sept.	0.51	0.005	102	-	-

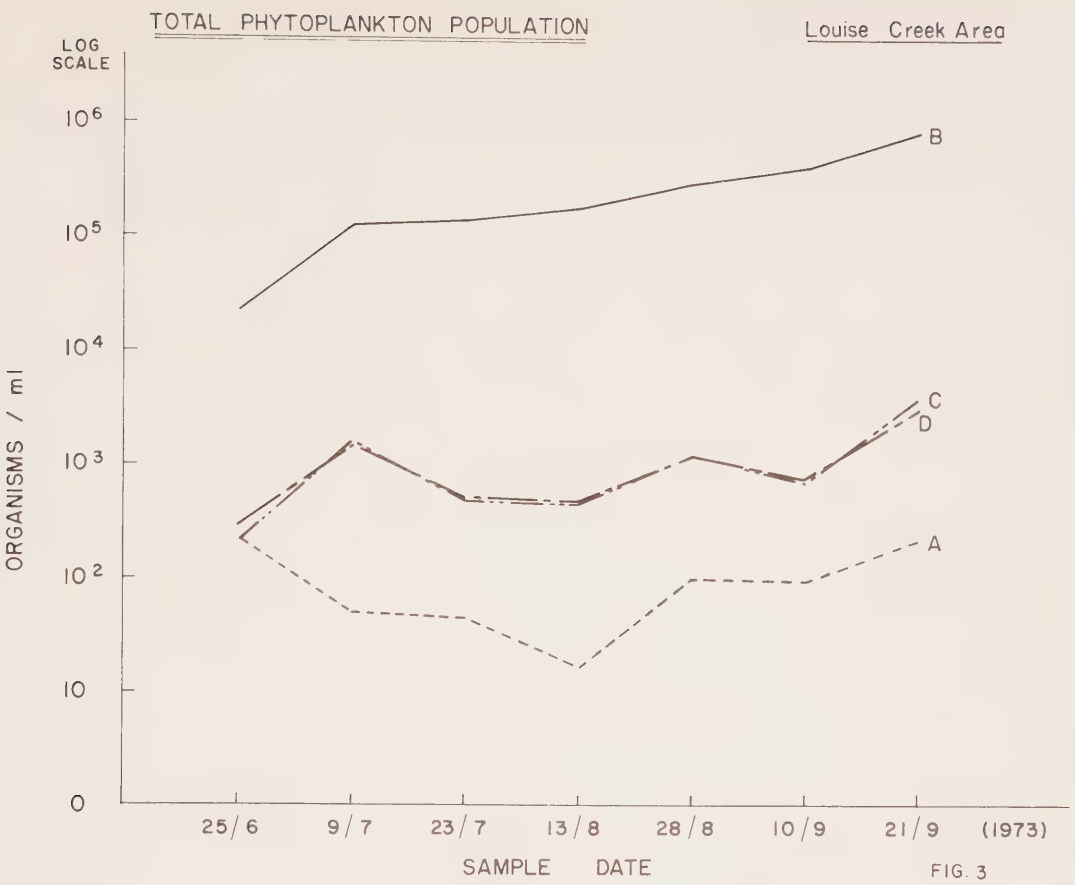
TOTAL PHYTOPLANKTON POPULATION
Louise Creek Area
LOG SCALE
ORGANISMS / ml
10^6
10^5
10^4
10^3
10^2
10
0
B
C
D
A
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 3

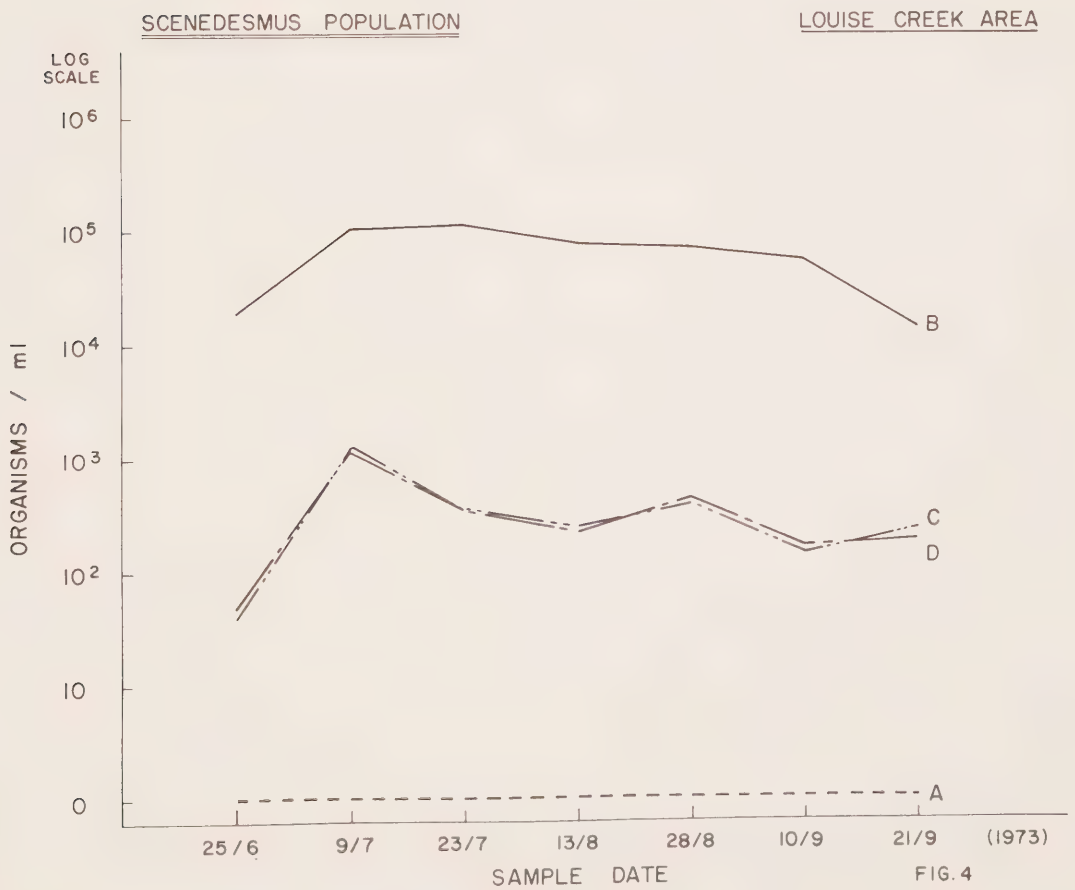
SCENEDESMUS POPULATION
LOUISE CREEK AREA
LOG SCALE
ORGANISMS / ml
10^6
10^5
10^4
10^3
10^2
10
0
B
C
D
A
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 4

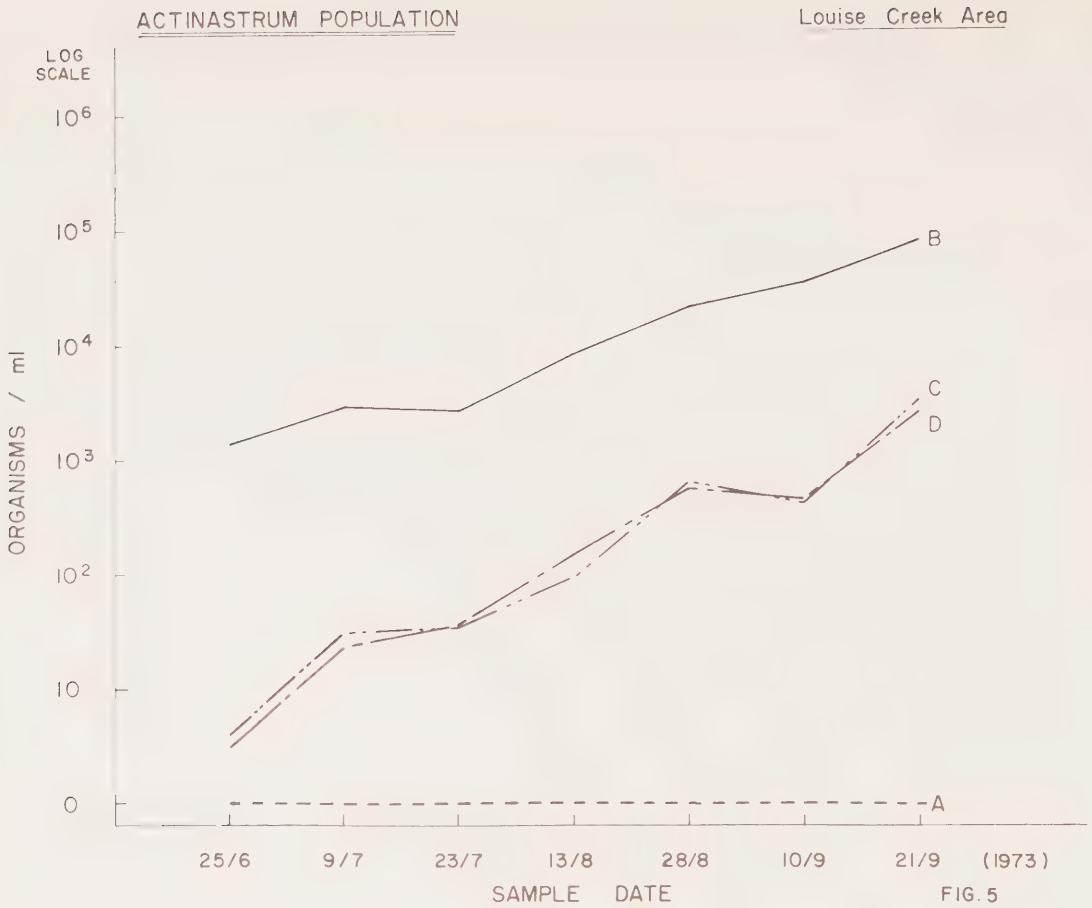
ACTINASTRUM POPULATION
Louise Creek Area
LOG SCALE
ORGANISMS / ml
10^6
10^5
10^4
10^3
10^2
10
0
B
C
D
A
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 5

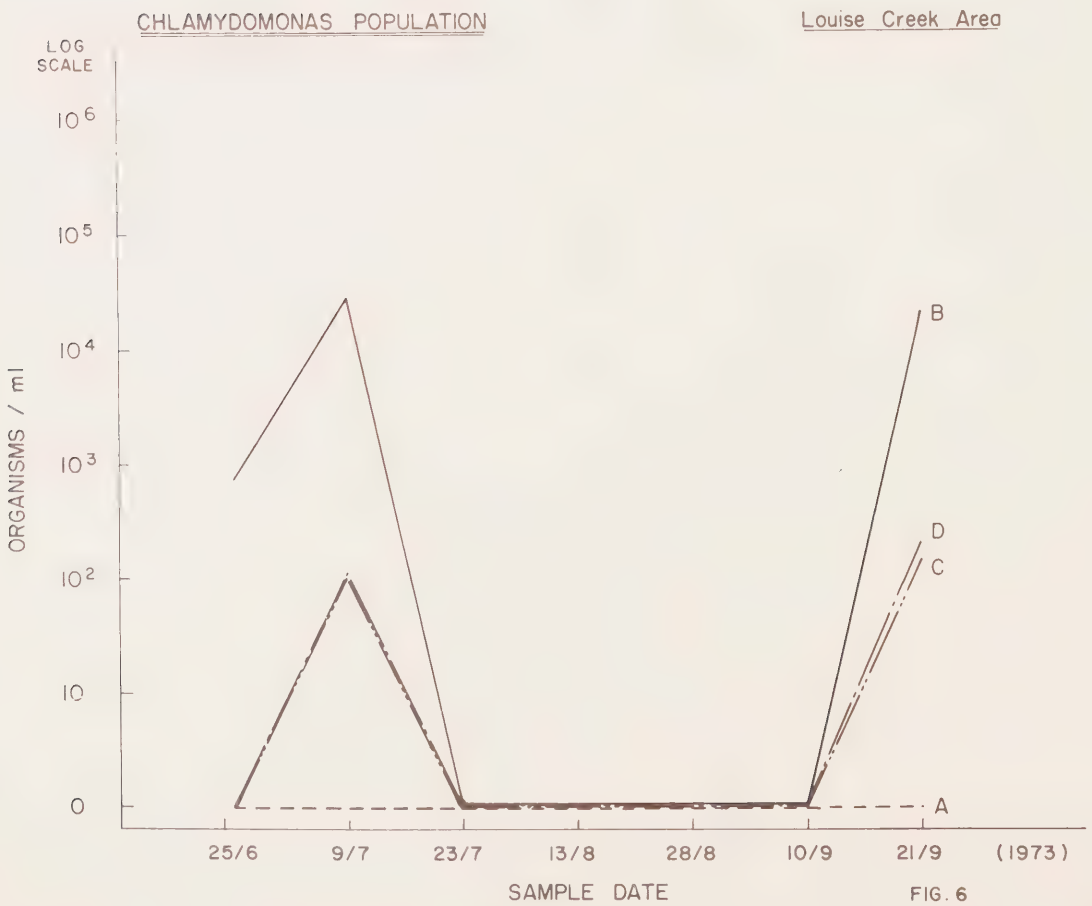
CHLAMYDOMONAS POPULATION
Louise Creek Area
LOG SCALE
ORGANISMS / ml
10^6
10^5
10^4
10^3
10^2
10
0
B
D
C
A
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 6

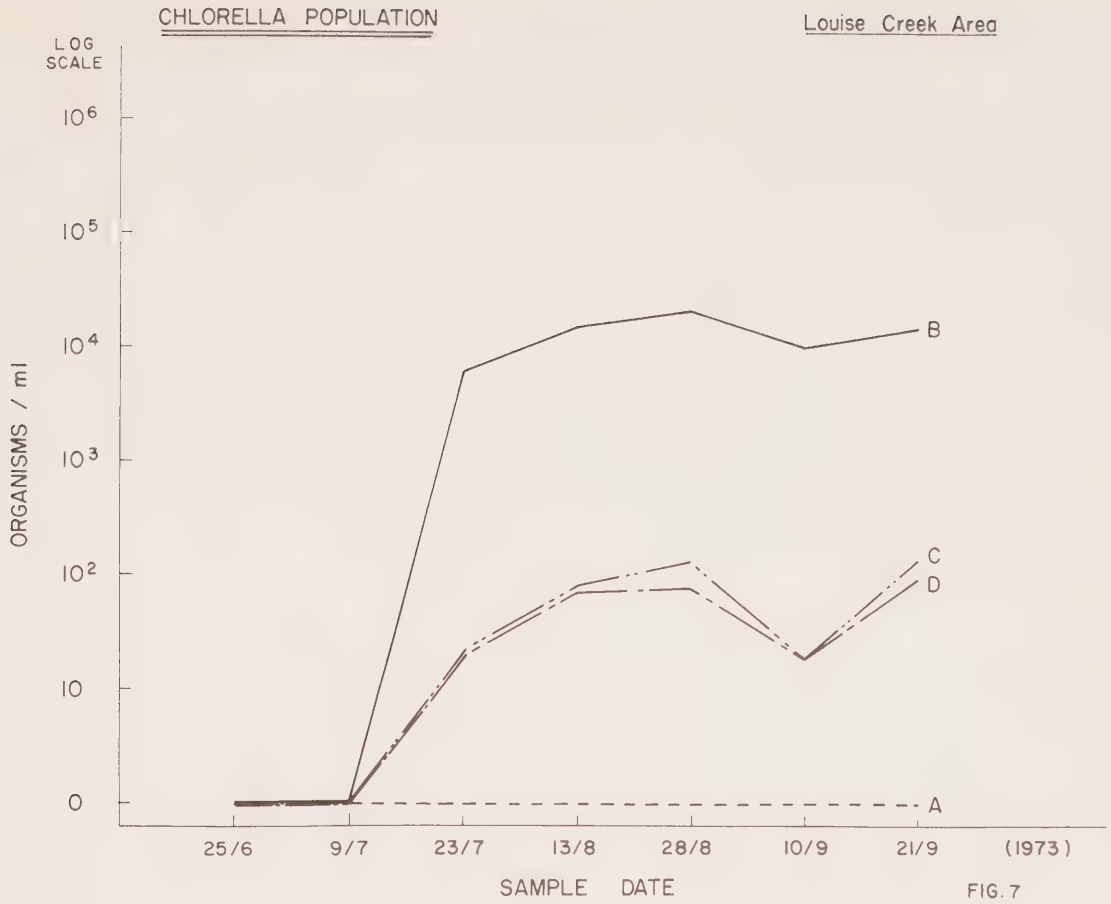
CHLORELLA POPULATION
Louise Creek Area
LOG SCALE
ORGANISMS / ml
10⁶
10⁵
10⁴
10³
10²
10
0
B
C
D
A
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 7

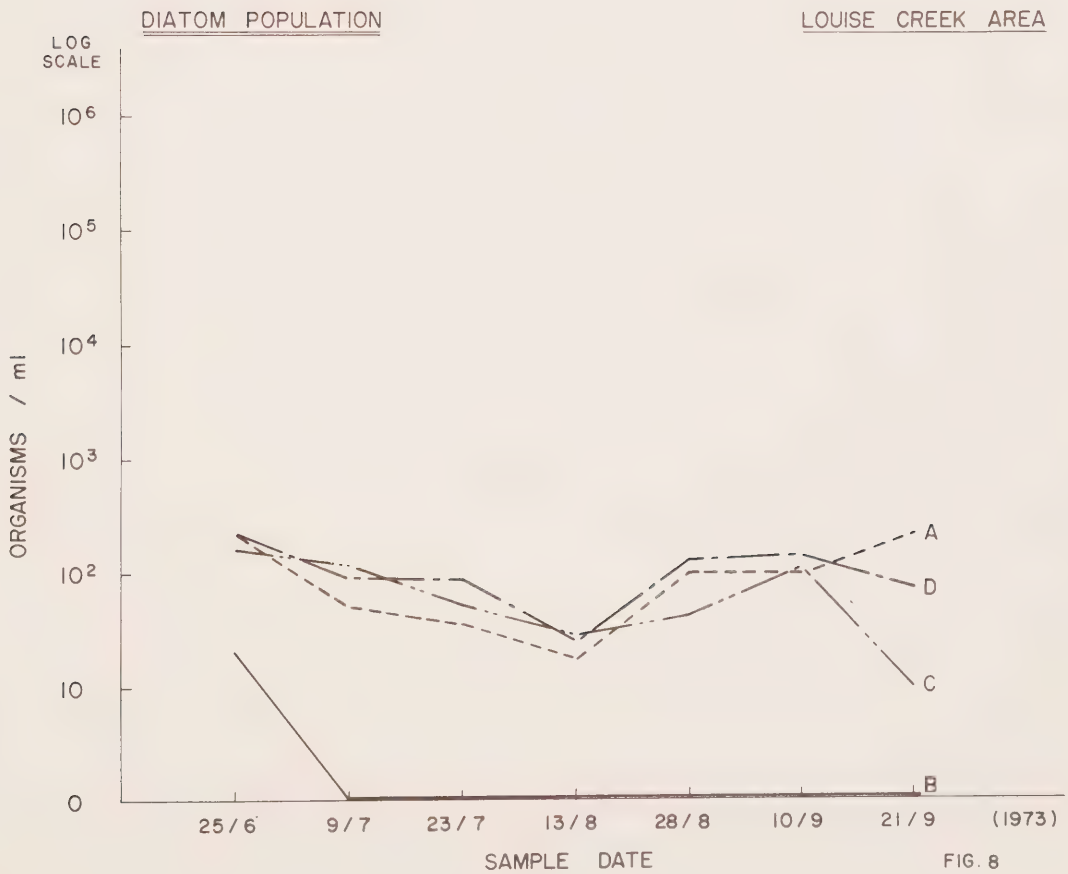
DIATOM POPULATION
LOUISE CREEK AREA
LOG SCALE
ORGANISMS / ml
10⁶
10⁵
10⁴
10³
10²
10
0
A
D
C
B
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 8

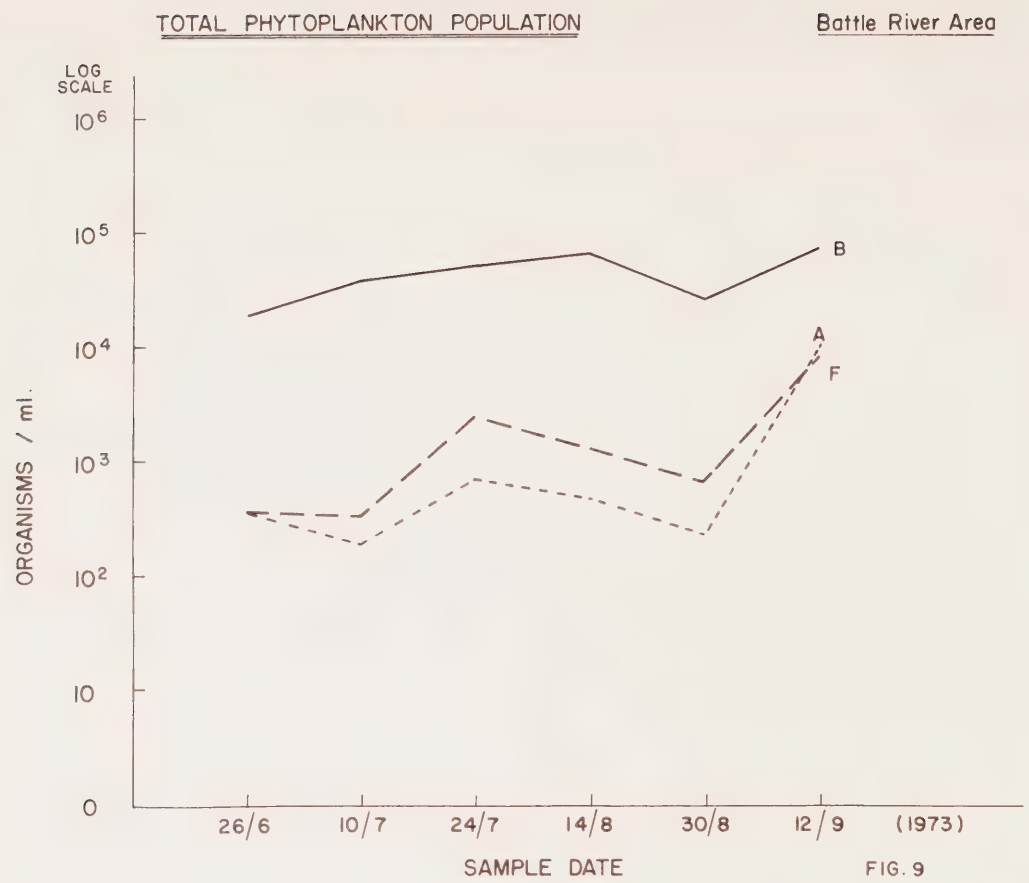
TOTAL PHYTOPLANKTON POPULATION
Battle River Area
LOG SCALE
10^6
10^5
10^4
10^3
10^2
10
0
ORGANISMS / ml.
B
A
F
26/6
10/7
24/7
14/8
30/8
12/9
(1973)
SAMPLE DATE

FIG. 9

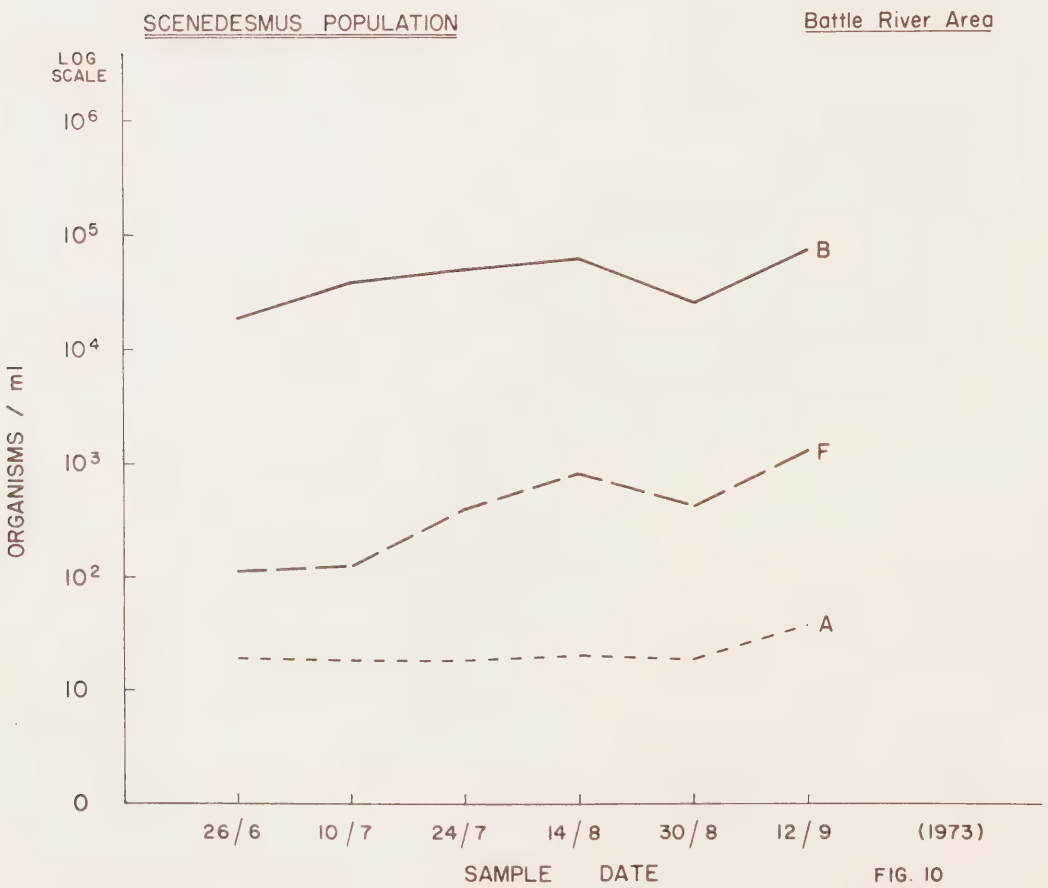
SCENEDESMUS POPULATION
Battle River Area
LOG SCALE
10^6
10^5
10^4
10^3
10^2
10
0
ORGANISMS / ml
B
F
A
26/6
10/7
24/7
14/8
30/8
12/9
(1973)
SAMPLE DATE

FIG. 10

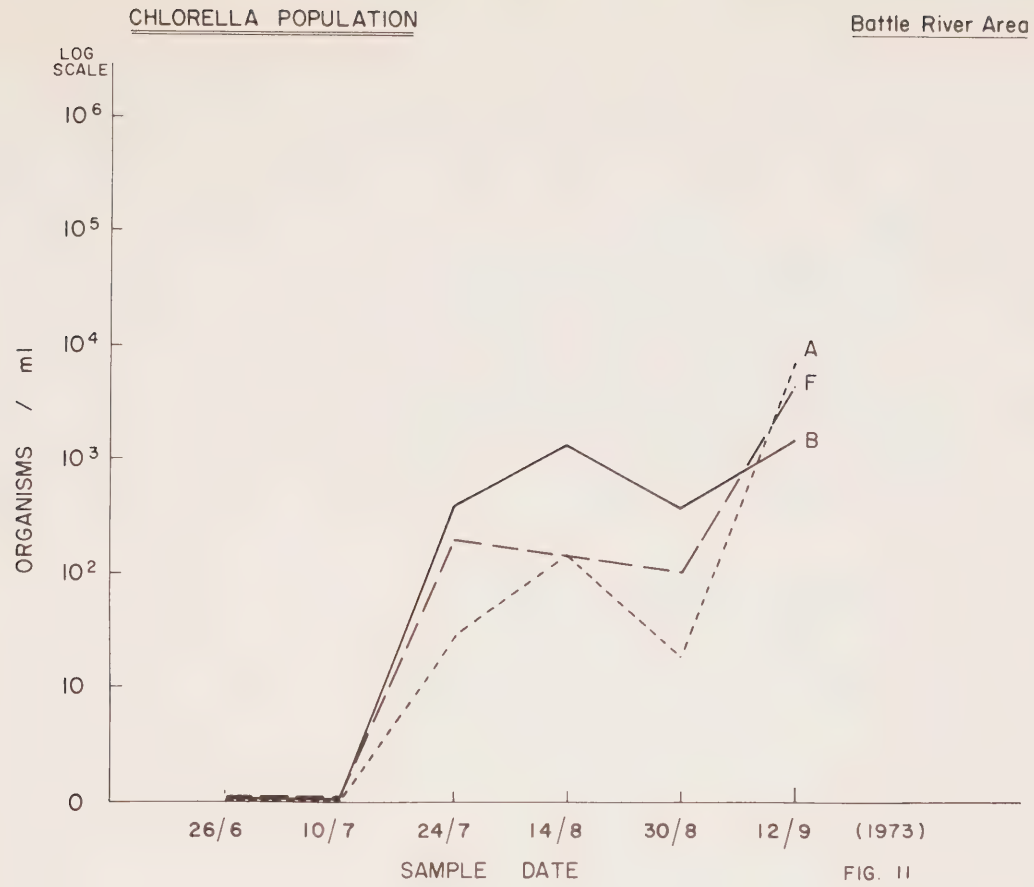
CHLORELLA POPULATION
Battle River Area
LOG SCALE
10^6
10^5
10^4
10^3
10^2
10
0
ORGANISMS / ml
A
F
B
26/6
10/7
24/7
14/8
30/8
12/9
(1973)
SAMPLE DATE

FIG. 11

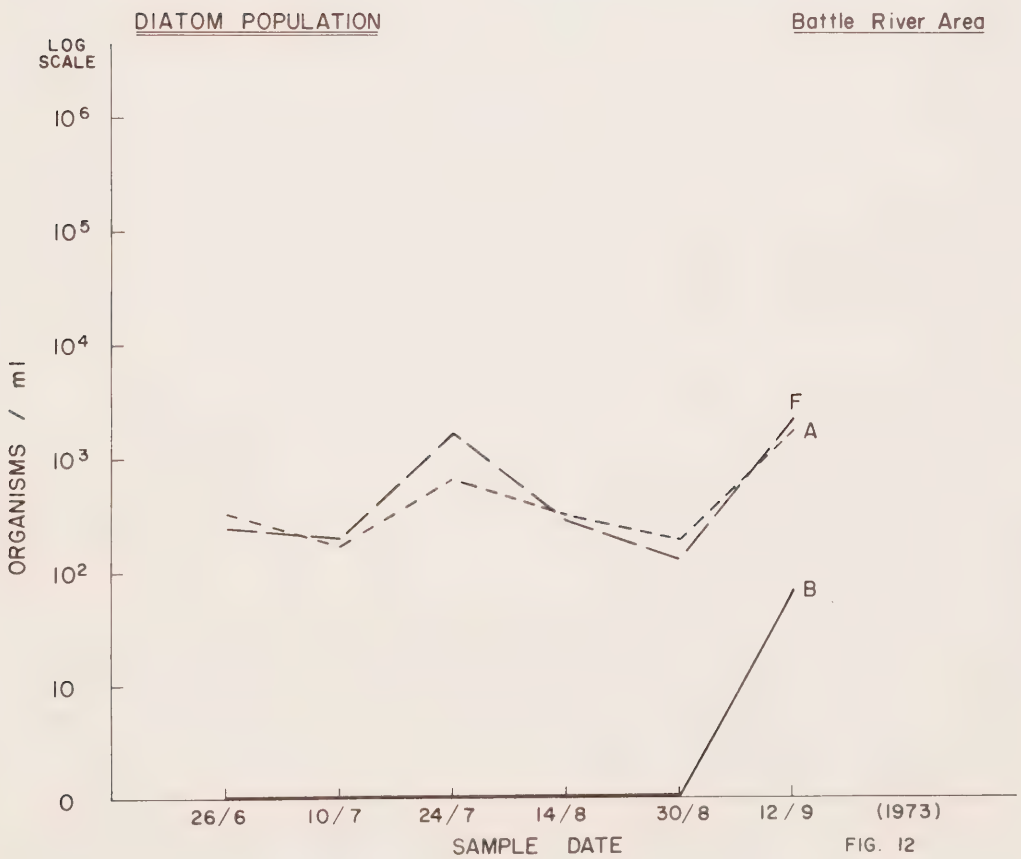
DIATOM POPULATION
Battle River Area
LOG SCALE
10^6
10^5
10^4
10^3
10^2
10
0
ORGANISMS / ml
F
A
B
26/6
10/7
24/7
14/8
30/8
12/9
(1973)
SAMPLE DATE

FIG. 12

The flow of Louise Creek declined throughout the study period from a high of 3.77 $m^3 s^{-1}$ to a low of 0.51 $m^3 s^{-1}$. The flow of the Louise Creek oxidation pond was greatest on 9th July, and thereafter declined to a low of 0.005 $m^3 s^{-1}$. The dilution of the Louise Creek effluent is also included in Table 1. The least dilututions occurred when the effluent flow was greatest, on 9 July, when the dilution ratio was 57:1. Greatest dilution occurred on 13 August when the dilution ratio was 396:1. The greatest flow from the Ponoka oxidation pond also occurred on 9 July, but over much of the study period, it was relatively consistent at 0.014 $m^3 s^{-1}$. The Battle River at Ponoka dropped steadily throughout the study period to a low of 0.35 $m^3 s^{-1}$ on 12 Sept. At that time the dilution ratio of the effluent was 25:1.

6.2 Phytoplankton Populations

The results of the phytoplankton counts are shown in Figures 3-12. The curve designations correspond with the sampling point locations previously given. Complete data are given in Appendix I and II.* The total phytoplankton population for the Louise Creek effluent (Fig. 3) increased steadily throughout the study period, reaching a high of 848,000 organisms/ml. The phytoplankton population in Louise Creek above the effluent outfall averaged approximately 100 organisms/ml with lesser numbers during the mid part of the study period. Below the effluent outfall, there was an average of approximately 1,000 organisms/ml throughout most of the study period.

The most common organism in the effluent from the Louise Creek oxidation pond was *Scenedesmus quadricauda*. *S. falcata* was also present and was included in the counts given in Fig.4. *Scenedesmus* reached a peak of 144,000 organisms/ml in late July and thereafter declined to 14,000 organisms/ml by late September. *Scenedesmus* was not observed in the water of Louise Creek above the effluent outfall. In the creek below the outfall an average of 775 organisms/ml was counted.

Organisms of the genus *Actinastrum* were not found in Louise Creek above the outfall, but were present in the oxidation pond effluent (Fig. 5). They steadily increased in the effluent during the study period, to a high of 798,000 organisms/ml. In the creek below the outfall, *Actinastrum* steadily increased throughout the study period to approximately 3,000 organisms/ml.

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* Appendices available on application to Manager, ALUR Program, Northern Natural Resources and Environment Branch, Dept. Indian Affairs and Northern Development, OTTAWA, K1A 0H4

Populations of *Chlamydomonas* were present in the Louise Creek effluent at the beginning and end of the study period, but disappeared during the month of August.

Populations of a species of *Chlorella* were not present in Louise Creek above the effluent outfall, but averaged approximately 10,000 organisms/ml in the effluent (Fig. 7). Lower down in the creek these organisms ranged from 100-1000 organisms/ml over much of the study period.

Diatoms were present throughout Louise Creek where they averaged about 100 organisms/ml throughout the study period (Fig. 8). They were also initially observed in the Louise Creek effluent, but were not observed at this sampling point later than June.

In the Battle River, the total phytoplankton population increased during the study period, both above and below the oxidation pond outfall (Fig. 9). It reached a peak of over 9,000 organisms/ml upstream of the outfall during September. The effluent increased slightly in total population of phytoplankton during the study period to a high of over 70,000 organisms/ml.

The most common phytoplankton organism found in the Battle River study was *Scenedesmus quadricauda*. *S.falcata* is also present and is included in the data in Figure 10. *Scenedesmus* organisms were present upstream of the effluent outfall where they averaged about 20 organisms/ml over most of the study period. In the effluent, *Scenedesmus* averaged about 44,000 organisms/ml. Downstream from the outfall, *Scenedesmus* increased from 100 to 1300 organisms/ml during the study period.

Chlorella appeared in early July and tended to increase during the summer, both above and below the Battle River outfall and in the effluent itself (Fig. 11). Diatoms were present in the Battle River, above and below the outfall, where they ranged from about 100-1000 organisms/ml (Fig. 12).

6.3 Bacteriological Data

The bacteriological data for the Louise Creek area and for the Battle River area are given in Table 2 and 3 respectively. Although not a direct part of this study they are included to give an indication of the possible downstream levels of bacteria. Fecal coliform organisms were recorded upstream of the Louise Creek effluent outfall on one occasion. Chlorination of the Louise Creek effluent resulted in the absence of fecal coliform organisms from the effluent during the latter part of the study period.

Table 2

BACTERIOLOGICAL DATA

LOUISE CREEK AREA

SAMPLE DATE	TOTAL COLIFORM				TOTAL COLIFORM				STANDARD PLATE COUNT X 1000			
	A	B	C	D	A	B	C	D	A	B	C	D
10/7/73	0	38	8.2	3.6	0	2.0	1.8	0	100	320	140	900
24/7/73	170	1800	1600	29	6.8	4.5	4.0	3.7	1.5	64	2.5	1.2
14/8/73	0	1800	39	93	0	0	0	0	3.0	1,750	3.0	3.0
29/8/73	0	0	15.0	0	0	0	0	0	3.0	2,440	3.0	3.0
12/9/73	3.6	460	3.0	-	0	0	0	-	0.04	3.0	0.4	-
23/9/73	0	2.0	4.5	-	0	0	0	-	0.12	3.3	0.6	-

Table 3

BACTEROLOGICAL DATA BATTLE RIVER AREA

SAMPLE DATE	TOTAL COLIFORM						FECAL COLIFORM						STANDARD PLATE COUNT X 1000					
	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
10/7/73	540	1800	540	540	350	540	17.0	350	14.0	12.0	14.0	21.0	1.3	36	0.6	1.0	1.5	800
24/7/73	540	1800	240	350	350	350	20.0	52	33	40	40	4.0	1.2	30	1.3	2.5	0.5	1.5
14/8/73	49	-	240	110	95	130	4.5	-	4.5	4.0	3.6	4.0	3	-	15	14.5	3	11.5
30/8/73	27	280	40	920	350	110	0	0	0	6.8	2.0	0	1.3	12.9	2.3	3.1	1.3	1.8
12/9/73	220	32	110	-	-	-	4.5	0	2.0	-	-	-	0.4	77	3	-	-	-

Table 4

LOUISE CREEK WATER QUALITY DATA

Sample Date	June 25, 1973				July 9, 1973				July 23, 1973			
Sample Point	A	B	C	D	A	B	C	D	A	B	C	D
Dissolved Oxygen (mg/l)	10.0	8.0	9.5	9.5	9.3	9.0	9.3	9.2	9.0	10.0	9.0	9.0
Temperature ^{o}C	6.1	16.7	6.1	6.1	12.1	19.0	12.5	12.5	12.2	18.9	12.2	12.2
$B.O.D._5$ (mg/l)	1	4	1	-	2	32	2	-	1	21	1	-
C.O.D. (mg/l)	4	69	1	-	1	107	1	-	1	120	1	-
Suspended Solids (mg/l)	17	19	14	-	8	35	5.5	-	2	40	8	-
Volatile Susp. Solids (mg/l)	1	13	1	-	1	31	1	-	1	35	1	-
Total Residue (mg/l)	95	180	90	-	96	240	90	-	92	198	-	-
Fixed Residue (mg/l)	60	95	85	-	60	106	84	-	78	88	-	-
pH	8.0	7.7	8.0	-	8.2	7.3	8.2	-	8.2	7.3	8.2	-
Alkalinity as $CaCo_3$ (mg/l)	70	115	70	-	71	113	71	-	72	110	71	-
Ammonia Nitrogen (mg/l)	0.1	4.0	0.1	-	0.1	7	0.1	-	0.1	5.2	0.1	-
Nitrate Nitrogen (mg/l)	0.1	0.19	0.1	-	0.11	0.1	0.16	-	0.1	0.1	0.13	-
Nitrite Nitrogen (mg/l)	0.01	0.019	0.01	-	0.01	0.02	0.01	-	0.01	0.01	0.02	-
Organic Nitrogen (mg/l)	-	-	-	-	-	-	-	-	-	-	-	-
Total Phosphate (mg/l)	0.04	1.3	0.05	-	0.01	2.10	0.03	-	0.03	2.2	0.12	-
Turbidity (j.t.u.)	3.8	7.4	3.7	-	1	11	1	-	6	14	4	-
Total Hardness (mg/l)	75	95	95	-	76	86	78	-	72	88	77	-
Chloride (mg/l)	4	14	2	-	5	14	5	-	4	24	4	-
Total Carbon (mg/l)	21	50	22	-	18	63	24	0	20	69	21	-
Inorganic Carbon (mg/l)	20	31	21	-	18	34	21	-	19	34	20	-
Organic Carbon (mg/l)	1	19	1	-	1	29	3	-	1	38	2	-
Sulphate (mg/l)	-	-	-	-	5	7	6	-	5	5	6	-
Total Chlorine (mg/l)	-	1.8	-	-	-	0.02	-	-	-	1.3	-	-

Table 4 (Cont'd)

LOUISE CREEK WATER QUALITY DATA

Sample Date	Aug. 13, 1973				Aug. 28, 1974				Sept. 10, 1973			
Sample Point	A	B	C	D	A	B	C	D	A	B	C	D
Dissolved Oxygen (mg/l)	9.5	11.5	9.3	9.3	9.6	9.6	9.5	9.6	8.5	11.8	8.7	8.7
Temperature ^{o}C	11.1	21.0	11.0	11.0	9.0	18.0	8.0	8.0	12.0	20.0	12.5	12.5
B.O.D.$_5$ (mg/l)	1	21	1	-	2	17	2	-	2	11	2	-
C.O.D. (mg/l)	1	128	-	-	1	135	1	-	1	113	2	-
Suspended Solids (mg/l)	2	40	8	-	3	36	6	-	2	32	2	-
Volatile Susp. Solids (mg/l)	1	35	1	-	1	34	2	-	1	28	1	-
Total Residue (mg/l)	78	232	90	-	92	218	90	-	84	212	86	-
Fixed Residue (mg/l)	72	108	46	-	80	142	72	-	56	88	70	-
pH	7.9	7.4	8.2	-	8.1	7.1	8.1	-	7.4	7.1	7.9	-
Alkalinity as $CaCo_3$ (mg/l)	66	108	71	-	71	110	74	-	74	94	69	-
Ammonia Nitrogen (mg/l)	-	-	-	-	0.1	8.0	0.1	-	0.1	3.5	0.1	-
Nitrate Nitrogen (mg/l)	-	-	-	-	0.1	0.1	0.13	-	0.1	0.1	0.1	-
Nitrite Nitrogen (mg/l)	-	-	-	-	0.01	0.01	0.01	-	0.01	0.01	0.01	-
Organic Nitrogen (mg/l)	-	-	-	-	0.11	0.83	0.16	-	0.4	7.9	0.6	-
Total Phosphate (mg/l)	0.1	1.9	0.1	-	0.1	2.3	0.1	-	0.10	2.0	0.10	-
Turbidity (j.t.u.)	2	12	6	-	5	20	5	-	6	17	5	-
Total Hardness (mg/l)	77	92	77	-	72	93	81	-	76	81	77	-
Chloride (mg/l)	10	20	14	-	4	21	5	-	1	15	9	-
Total Carbon (mg/l)	21	74	22	-	21	76	21	-	20	69	32	-
Inorganic Carbon (mg/l)	19	34	20	-	20	32	20	-	19	27	32	-
Organic Carbon (mg/l)	2	40	2	-	1	44	1	-	1	42	0	-
Sulphate (mg/l)	7	8	7	-	5	7	5	-	6	3	5	-
Total Chlorine (mg/l)	-	2	-	-	-	1.6	-	-	-	2.4	-	-

Table 4 (Cont'd)

LOUISE CREEK WATER QUALITY DATA

Sample Date	Sept. 21, 1973											
Sample Point	A	B	C	D	A	B	C	D	A	B	C	D
Dissolved Oxygen (mg/l)	9.5	9.7	9.3	9.6								
Temperature ^{o}C	7.5	11.0	8.0	8.0								
B.O.D.$_5$ (mg/l)	1	15	1	-								
C.O.D. (mg/l)	1	110	1	-								
Suspended Solids (mg/l)	2	32	2	-								
Volatile Susp. Solids (mg/l)	2	31	2	-								
Total Residue (mg/l)	56	204	68	-								
Fixed Residue (mg/l)	36	92	64	-								
pH	8.0	7.2	8.0	-								
Alkalinity as $CaCO_3$ (mg/l)	71	90	71	-								
Ammonia Nitrogen (mg/l)	0.1	0.1	1.5	-								
Nitrate Nitrogen (mg/l)	0.1	0.1	0.13	-								
Nitrite Nitrogen (mg/l)	0.01	0.03	0.01	-								
Organic Nitrogen (mg/l)	0.13	0.20	4.0	-								
Total Phosphate (mg/l)	0.1	1.42	0.1	-								
Turbidity (j.t.u.)	1.5	14	3	-								
Total Hardness (mg/l)	114	112	114	-								
Chloride (mg/l)	12	29	13	-								
Total Carbon (mg/l)	21	65	21	-								
Inorganic Carbon (mg/l)	20	25	20	-								
Organic Carbon (mg/l)	1	40	1	-								
Sulphate (mg/l)	5	5	5	-								
Total Chlorine (mg/l)	-	3.0	-	-								

Table 5

BATTLE RIVER WATER QUALITY DATA

Sample Date	June 26, 1974				July 10, 1974				July 24, 1974			
Sample Point	A	B	C	D	A	B	C	D	A	B	C	D
Dissolved Oxygen (mg/1)	-	-	-	-	6.6	6.5	6.3	6.4	8.0	7.0	9.0	8.5
Temperature ^{o}C	17	20	17	17	21	18	21	21	21	19.5	21	21
$B.O.D._5$ (mg/1)	2	16	-	4	3	20	-	4	5	20	-	8
C.O.D. (mg/1)	56	103	-	61	51	100	-	44	44	159	-	48
Suspended Solids (mg/1)	16	15	-	18	14	44	-	11	15	53	-	11
Volatile Susp. Solids (mg/1)	2	5	-	1	1	35	-	1	3	45	-	3
Total Residue (mg/1)	415	840	-	405	302	826	-	342	286	846	-	514
Fixed Residue (mg/1)	265	710	-	310	208	676	-	260	214	694	-	362
pH	8.0	8.2	-	8.0	8.2	8.0	-	8.1	8.2	8.4	-	8.3
Alkalinity as $CaCO_3$ (mg/1)	245	550	-	245	204	518	-	206	211	501	-	212
Ammonia Nitrogen (mg/1)	0.15	15.6	-	0.20	0.1	13.8	-	0.1	0.1	9.0	-	0.1
Nitrate Nitrogen (mg/1)	0.18	0.1	-	0.16	0.1	0.12	-	0.1	0.1	0.1	-	0.1
Nitrite Nitrogen (mg/1)	0.067	0.01	-	0.01	0.02	0.02	-	0.01	0.01	3.2	-	0.1
Organic Nitrogen (mg/1)	-	-	-	-	-	-	-	-	-	-	-	-
Total Phosphate (mg/1)	0.36	7.5	-	0.36	0.51	7.55	-	0.24	0.4	5.4	-	0.3
Tubidity (j.t.u.)	4.8	11	-	6.3	1	5	-	1	4	16	-	8
Total Hardness (mg/1)	215	185	-	205	190	220	-	185	173	257	-	173
Chloride (mg/1)	18	40	-	13	6	36	-	5	19	40	-	3
Total Carbon (mg/1)	81	160	-	82	70	174	-	89	65	160	-	68
Inorganic Carbon (mg/1)	64	140	-	65	53	134	-	62	49	125	-	50
Organic Carbon (mg/1)	17	20	-	17	17	40	-	17	16	35	-	18
Sulphate (mg/1)	-	-	-	-	25	100	-	73	16	100	-	15

Table 5 (Cont'd)

BATTLE RIVER WATER QUALITY DATA

Sample Date	Aug. 14, 1973				Aug. 30, 1973				Sept. 12, 1973			
Sample Point	A	B	C	D	A	B	C	D	A	B	C	D
Disolved Oxygen (mg/l)	6.6	6.5	6.7	6.7	7.8	7.5	8.0	8.0	8.4	9.7	8.9	8.6
Temperature °C	22	17	22	22	14.5	16	14	14	15	16	15	15
B.O.D.$_5$ (mg/l)	1	24	-	1	2	18	-	2	4	30	-	8
C.O.D. (mg/l)	58	103	-	58	49	71	-	45	40	64	-	44
Suspended Solids (mg/l)	10	41	-	15	7	19	-	7	10	20	-	14
Volatile Susp. Solids (mg/l)	3	35	-	1	2	16	-	2	4	15	-	4
Total Residue (mg/l)	366	830	-	296	318	818	-	320	360	818	-	366
Fixed Residue (mg/l)	274	729	-	266	226	666	-	188	250	676	-	252
pH	7.4	8.4	-	7.1	8.1	7.9	-	8.0	8.0	7.8	-	8.0
Alkalinity as $CaCO_3$ (mg/l)	170	482	-	138	214	498	-	218	251	318	-	253
Ammonia Nitrogen (mg/l)	-	-	-	-	0.1	0.1	-	0.1	5.0	2.5	-	4.0
Nitrate Nitrogen (mg/l)	-	-	-	-	0.2	9.1	-	0.32	0.1	1.3	-	0.1
Nitrite Nitrogen (mg/l)	-	-	-	-	0.01	0.01	-	0.01	0.08	0.86	-	0.18
Organic Nitrogen (mg/l)	-	-	-	-	-	-	-	-	18.5	4.2	-	20.0
Total Phosphate (mg/l)	0.2	4.5	-	0.2	0.15	4.04	-	0.16	0.11	3.91	-	0.18
Turbidity (j.t.u.)	6	8	-	4	5	10	-	5	4	9	-	4
Total Hardness (mg/l)	197	197	-	183	192	244	-	181	208	295	-	210
Chloride (mg/l)	23	50	-	33	5	46	-	7	8	44	-	11
Total Carbon (mg/l)	71	156	-	67	71	148	-	72	80	148	-	81
Inorganic Carbon (mg/l)	48	123	-	43	54	134	-	55	62	122	-	65
Organic Carbon (mg/l)	23	33	-	24	17	14	-	17	18	26	-	16
Sulphate (mg/l)	33	134	-	32	25	180	-	23	26	103	-	27

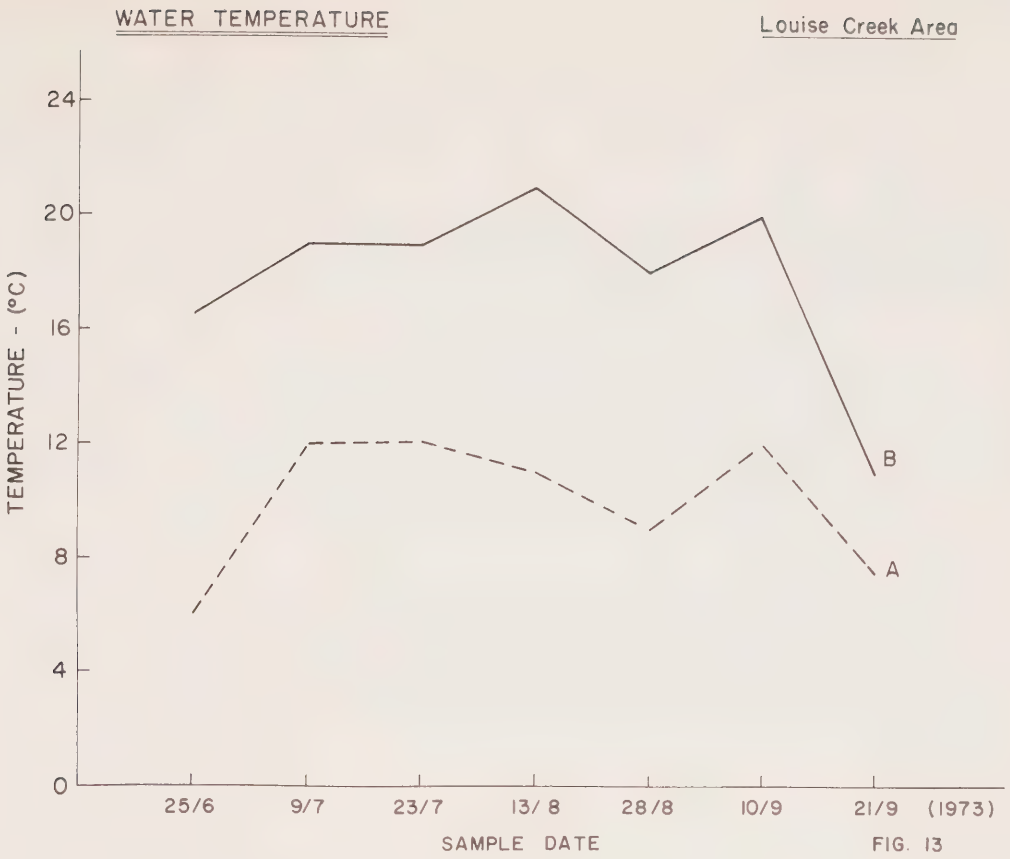
WATER TEMPERATURE
Louise Creek Area
TEMPERATURE - (°C)
24
20
16
12
8
4
0
B
A
25/6
9/7
23/7
13/8
28/8
10/9
21/9
(1973)
SAMPLE DATE

FIG. 13

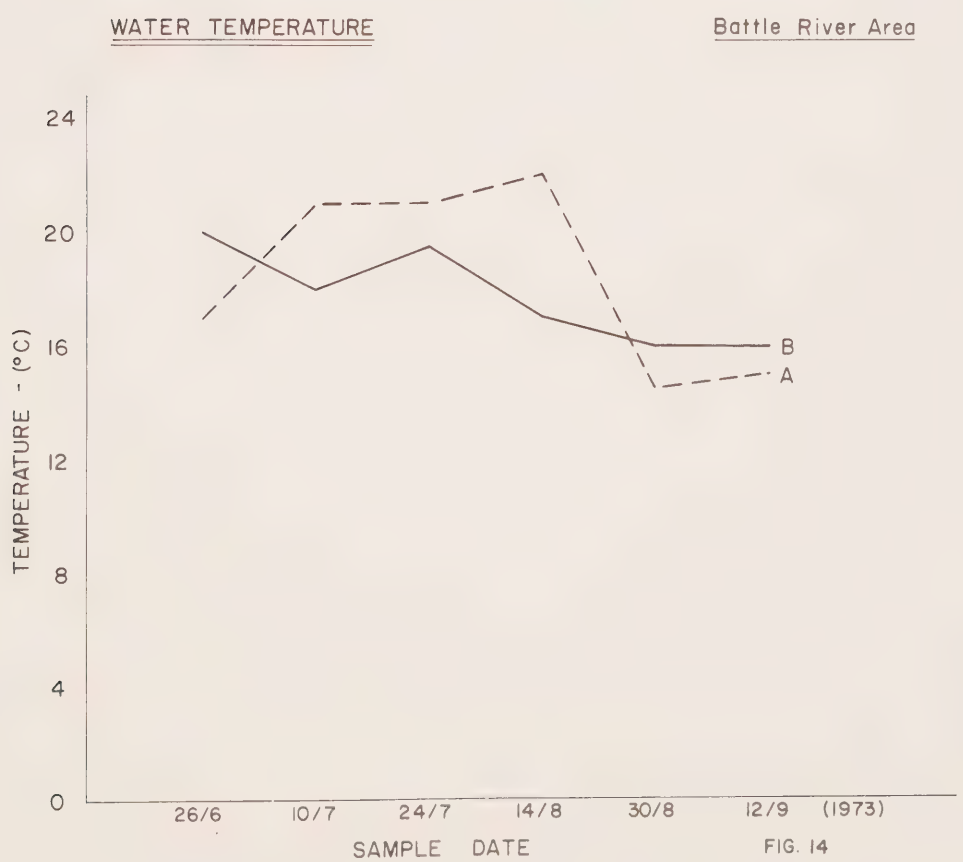
WATER TEMPERATURE
Battle River Area
TEMPERATURE - (°C)
24
20
16
12
8
4
0
B
A
26/6
10/7
24/7
14/8
30/8
12/9
(1973)
SAMPLE DATE

FIG. 14

6.4 Water Quality Data, Chemical and Physical Parameters

Water quality data are given in Table 4 and 5 for the Louise Creek area and the Battle River area respectively.

The level of dissolved oxygen at all sampling points in the Louise Creek area remained high throughout the study period. Slightly lower levels were recorded in the Battle River area.

The water temperature of Louise Creek and its contributory effluent is expressed graphically in Fig. 13 and that of the Battle River area in Fig. 14. The temperature of the Louise Creek effluent was consistently higher than that of Louise Creek itself. Conversely, the temperature of the Battle River often exceeded that of its contributing effluent.

Measurements of BOD_5 and suspended solids in the Louise Creek effluent ranged from 4-32 mg/l and from 19-40 mg/l respectively. In the Battle River effluent, BOD_5 and suspended solids ranged from 16-30 mg/l and from 15-53 mg/l respectively.

7. DISCUSSION

7.1 Phytoplankton Population

The results of this study indicate that large numbers of algae are released from sewage oxidation ponds during the summer months. The green alga *Scenedesmus quadricauda* was the most abundant organism in the effluent from the Louise Creek oxidation pond in early summer. It slowly declined in numbers throughout the summer. Conversely, a species of *Actinastrum* was low in numbers in this effluent in early summer, but increased considerably and continually throughout the study period. In terms of total numbers, these two organisms have the greatest effect on the receiving waters, especially as neither were observed upstream of the Louise Creek oxidation pond outfall. Below the outfall, *Scenedesmus* and *Actinastrum* were observed in maximum concentrations of 1,300 and 3,300 organisms/ml respectively. When comparing populations of *Scenedesmus* with other single-celled organisms such as *Actinastrum*, it should be remembered that *Scenedesmus quadricauda* usually occurs as a small colony of four joined cells. A concentration of 1,300 organisms/ml of *Scenedesmus quadricauda* would therefore contain approximately 5,200 cells/ml.

Scenedesmus quadricauda was also the most abundant organism in the Battle River effluent, although in contrast to Louise Creek, *Scenedesmus* was found upstream of the effluent outfall, an indication that the Battle River is already enriched. Downstream of the effluent outfall, *Scenedesmus* was found in increasing concentrations reaching over 2,000 organisms/ml.

Obviously, the dilution of the effluent with the receiving water will have an effect on the downstream concentration of effluent borne organisms. The least dilution of the Louise Creek effluent occurred in early July, at a time when the total count of effluent-borne organisms was low. At this time a peak in the total count downstream of the effluent was noted (Fig. 3).

A similar occurrence was noted in the Battle River, when its flow dropped to 0.35 $m^3 s^{-1}$, while the flow of the effluent remained at 0.014 $m^3 s^{-1}$. At this time, a total count of over 9,000 organisms/ml were recorded upstream from the effluent outfall and over 10,000 organisms/ml downstream of the outfall. Most of the upstream and downstream organisms were *Chlorella*, which was almost absent from the effluent. Under these conditions the already-enriched Battle River was stagnating and developing an algal bloom which was not related to the effluent.

The levels of phytoplankton recorded in Louise Creek were much higher than those previously reported by Krishnaswami and Slupsky (1970). The survey by these workers was carried out in June and July 1969 when they recorded a maximum concentration of 1163 plankton cells/litre, downstream of the effluent outfall, with only 20 cells/litre of *Scenedesmus quadricauda* being recorded in this same location. They concluded that "the waste water lagoon effluent discharged to Louise Creek affects adversely the population and variety of species of phytoplankton."

In the present study, the organisms in Louise Creek upstream of the effluent outfall were diatoms whose numbers remained relatively unchanged throughout the length of the creek on any particular sampling date. Louise Creek is, as has been noted, a torrential mountain stream which flows less than 3 km from its origin to its confluence with the Bow River. Under normal conditions a phytoplankton organism would take an hour at the most to be carried the whole length of the creek. Since the flow is torrential, mixing of the effluent with the creek water is immediate and oxygen levels are maintained in the water by constant agitation. In addition, the torrential action of the creek dislodges algae which are attached to submerged rocks, such as many species of diatoms, which will tend to increase the count of these organisms at the low end of the creek. There is no indication in this study that the standing phytoplankton population of Louise Creek is affected by the effluent. However, periphyton organisms downstream of the effluent outfall will probably be affected.

The Battle River is slow-flowing and samples collected downstream from the outfall, but on the opposite side of the river, indicated that little mixing was taking place. The effluent tended to remain on the same side of the river as it was discharged.

7.2 Physical and Chemical Parameters

There is a considerable difference in the physical and chemical parameters of the water of Louise Creek and its contributing effluent.

The effluent was consistently warmer than Louise Creek throughout the study period, although this temperature drop would have little effect on the effluent-borne phytoplankton, other than to reduce their metabolic rate. Conversely, the temperature of the Battle River often exceeded that of its contributing effluent. The maximum temperature recorded in Louise Creek was 12.5°C which is about 5°C less than that reported by Robinson (1972).

Ammonia nitrogen and organic nitrogen were considerably higher in the Louise Creek effluent than in the creek itself, although nitrate and nitrite nitrogen appeared comparable in the effluent and creek. The same was true of the Battle River and its effluent early in the summer, but later ammonia nitrogen and organic nitrogen in the river upstream of the outfall exceeded that of the effluent.

Organic carbon was considerably higher in the Louise Creek effluent than in Louise Creek, but there was less difference between the organic carbon in the Battle River and its effluent.

Total phosphate was much higher in the Battle River effluent than in the Louise Creek effluent, both being considerably higher than their respective receiving waters.

BOD_5 levels in the Louise Creek effluent ranged up to 35 mg/l, while that of the Battle River effluent ranged to 30 mg/l. The BOD_5 of Louise Creek was less than 2 mg/l and that of the Battle River was less than 5 mg/l. The maximum BOD_5 of the Battle River coincided with the maximum total count of the phytoplankton population in the river. Similarly the maximum BOD_5 of the Battle River effluent coincided with the peak effluent population of phytoplankton, while the maximum BOD_5 of the effluent occurred during July when the population of *Scenedesmus* was at its highest. In this effluent, BOD_5 levels feel throughout the remaining study period, as did the *Scenedesmus* population, but at the same time, the population of *Actinastrum* increased.

The evidence of this study suggests that *Scenedesmus* may have a greater effect on the BOD_5 test than *Actinastrum*, since there is an indication of a correlation between the level of BOD_5 and the population of *Scenedesmus* in the receiving water.

The BOD_5 downstream of the effluent outfall appears to be little affected by the effluent, remaining at the upstream level in most cases.

The algae released from the Louise Creek oxidation pond appeared at the lower end of the creek in a viable and healthy condition. There appeared to be no mortality occurring down the course of Louise Creek. Samples taken from up to 25.7 km downstream of the Louise Creek and Bow River confluence were examined and healthy specimens of *Scenedesmus* and *Actinastrum* were observed. Similarly in the Battle River, samples from 6.4 km below the outfall indicated a slight downstream increase in the population of *Scenedesmus*. There is an indication therefore, that effluent-borne algae do not have a detrimental effect on the receiving

water. However, it should not be construed that the effluent itself does not have a detrimental effect on the receiving waters, since the nutrients in the effluent will cause an increase in the productivity of periphyton organisms downstream from the outfall. Periphyton organisms were not considered in this study.

8. CONCLUSIONS

The identification and enumeration of phytoplankton populations above and at several points below the outfall from two sewage oxidation ponds has been completed.

The effluents from the oxidation ponds contained high levels of phytoplankton which ranged, in the Louise Creek effluent for example, up to more than 800,000 organisms/ml of effluent. Upstream from the oxidation pond outfall, the concentration of phytoplankton did not exceed 300 organisms/ml. The maximum downstream concentration of phytoplankton at this location was 3880 organisms/ml which occurred when there was little dilution of the effluent.

At points further downstream, the level of phytoplankton remained fairly constant on any given sampling date. The quality of the effluent ranged to a maximum BOD_5 of 32 mg/l, and a maximum SS of 53 mg/l, but through dilution in the receiving water this was reduced to a maximum BOD_5 of 4 mg/l in Louise Creek and a maximum BOD_5 of 8 mg/l in the Battle River. Suspended solids were similarly reduced. Dissolved oxygen levels downstream of the effluent discharge appeared to be little affected by the effluent.

The results of this study indicate that populations of phytoplankton which are released from the selected oxidation ponds remain fairly constant in the immediate downstream section of the receiving water. The phytoplankton population does not suddenly decline through die-off of the individual organisms, thereby exerting an oxygen demand which would be detrimental to the water quality. Observations indicate that, under low nutrient conditions, initial populations of phytoplankton remain constant, although it is probable that the population level slowly decreases with time, since the reproduction rate of the phytoplankton is likely to be insufficient to balance the numbers falling prey to secondary producers.

Where nutrient levels are higher, observations indicate that populations of phytoplankton may slowly increase downstream, although it is to be expected that there will be a change in species composition of the phytoplankton population, due to the varying abilities of different species to tolerate the new conditions.

There is also an indication that *Scenedesmus* may have a greater effect on the BOD_5 test than *Actinastrum* and may therefore be responsible for high BOD_5 measurements.

These conclusions indicate that the algal content of oxidation pond effluent is not necessarily deleterious to

the receiving water and underlines the need for an effluent test which will utilize other criteria to determine the treatment efficiency of oxidation ponds.

9. IMPLICATIONS AND RECOMMENDATIONS

The results of this project indicate that if oxidation ponds are used as sewage disposal methods by construction camps in the North, it is unlikely that the algal fraction of the effluent will be seriously detrimental to a flowing, receiving water. The most suitable receiving water is one which is constantly flowing with sufficient speed to effect good mixing of the effluent and receiving water and one which does not have a fluctuating flow which may at times become too low to be effective. There are, however, other considerations which must be taken into account.

A high level of treatment will only be achieved during the summer months when ponds are ice-free and algae can develop and provide aerobic conditions for degradation. During much of the year when ponds are covered by ice, treatment will be anaerobic and consequently poor. It may therefore be necessary to size oxidation ponds so that they have a one-year retention and can be drawn down at the end of the summer. This practice could result in extraordinarily large numbers of algae being discharged into a receiving water within a short time. It is therefore essential that the receiving water be of sufficient size and flowrate to absorb this load. Consideration must therefore be given to the selection of a suitable receiving water before deciding on the location of a camp.

A two-celled oxidation pond system would overcome the necessity to draw down at the end of the summer and would provide better than 1-year retention of the effluent. Using this system the first cell could be charged throughout the year and should be discharged to the second cell in the spring. The second cell should then be left for a year and discharged the following spring at a time when the algal population is lowest. The second cell would have a complete summer of treatment followed by a winter period when much of the algal biomass would settle out, producing an effluent of good quality for spring discharge. Each cell of a two-cell system should be of sufficient size for a one-year retention of effluent.

It is therefore recommended that, where single oxidation ponds are to be used for sewage treatment, they be sized for a one-year retention and be located so that the effluent (which should only be discharged during summer) can be discharged to a flowing water body of sufficient size and flowrate to allow no more than a 100-fold increase in the phytoplankton population. This could approximately be achieved by a 100:1 dilution of the effluent. Systems using two cells should be drawn down in spring when the algal population is low.

10. NEED FOR FURTHER STUDY

The results of this study have indicated that the algal fraction of algae-rich effluents may not be directly detrimental to a receiving water during the summer.

Originally, field sampling for this study was to continue into late fall 1973, but due to a breakdown of equipment and other restrictions, it was necessary to terminate the field sampling in September 1973. At the time the last samples were taken, high levels of algae were being recorded in the effluents from the oxidation ponds under study. Colder temperatures and decrease in daylight with the approach of freeze-up may adversely affect the phytoplankton population in the oxidation ponds. If a large percentage of the phytoplankton died off, this might exert an increased oxygen demand on the receiving water. There is, therefore, a need to determine the fate of oxidation pond algae during and after freeze-up.

The second phase of this project, which was to develop alternative tests for assessing the treatment efficiency of an oxidation pond, has not been started. There is an indication, from this study, that *Scenedesmus* has a greater effect on the BOD_5 test than does *Actinastrum*. There is, therefore, a need to investigate this finding and to determine the influence of various species of algae on the BOD_5 test.

There is also a need to define the light conditions under which little change in algal biomass takes place and to develop standard light conditions for a BOD_5 test which will eliminate interference by the algal fraction of the test wastewater.

11. REFERENCES

Caldwell, D.H. and Parker, D.D., 1973. Upgrading Lagoons. U.S. Env. Protect. Agency, Technol. Transfer Program.

Dawson, R.N., Grainge, J.W., Shaw, J.W. and Greenwood, J.L., 1973. Sewage Lagoon Systems. Supplementary Report A to the report Management of Waste from Arctic and Sub-Arctic Work Camps by Grainge, J.W., Edwards, R., Heuchert, K. and Shaw, J.W., 1973.

Edmondson, W.T., 1969. A Simplified Method for Counting Phytoplankton in A Manual on Methods for Measuring Primary Production in Aquatic Environments, ed. R.A. Vollenweider. IBP Handbook No. 12. Blackwell Scientific Publications, Oxford, England.

Grainge, J.W., Edwards, R., Heuchert, K. and Shaw, J.W., 1973. Management of Waste from Arcitc and Sub-Arctic Workcamps. Report No. 73-19 for the Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Dept. Indian Aff. North. Develop. Ottawa.

Krishnaswami, S.K. and Slupsky, J.W., 1970. Bow River Pollution and Limnological Survey, Banff National Park, Alberta. Summer, 1969. Div. Public Health Eng., Dept. Nat. Health Welfare, Edmonton, mimeo.

Prescott, G.W., 1970. How to Know the Freshwater Algae. Wm. C. Brown, Dubuque, Iowa. pp. 348.

Robinson, D.J., 1972. A Survey of Water Quality and Stream Invertebrate Communities in the Vicinity of Lake Louise and Lake O'Hara During the Summer of 1971. Can. Wildlife Serv. Nat. Hist. Parks Br. Dept. Indian Aff. North. Develop., Edmonton, mimeo.

Smith, G.M., 1950. The Freshwater Algae of the United States. McGraw-Hill, Toronto, 2nd Ed., pp. 719.

Standard Methods for the Examination of Water and Wastewater, 1971. 13th Ed. Amer. Pub. Health Assn., New York.

Ward, H.B., and Whipple, G.C., 1959. Fresh Water Biology, John Wiley and Sons, New York. 2nd Ed., pp. 1248.

Welch, P.S., 1948. Limnological Methods. McGraw-Hill, Toronto. pp. 381.

EFFECTS OF LAND SEWAGE DISPOSAL ON SUB-ARCTIC VEGETATION

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1. SUMMARY

A study was initiated to ascertain the effects of land sewage disposal on vegetation in Canada's north, and also to determine if such disposal, through nutrient enrichment, may be beneficial for the renovation of disturbed areas. Sewage was applied to two cut-lines in the subarctic boreal forest region, one near Fort Simpson, the other near Norman Wells, N.W.T. The vegetation on the treated areas was monitored after one growth season to assess the impact of the applied effluent. No adverse effects or changes in overall productivity, in terms of current biomass production, were evident. In the Fort Simpson study, production of the herb *Epilobium angustifolium*, was significantly increased on treated areas. Thus, some indication of the growth enhancement of pioneer species was seen.

Although it is expected that no harmful effects, and possibly some beneficial ones, may be engendered on terrestrial vegetation through land disposal of domestic sewage, it is not recommended that such a practice be considered as a major means of disposal for construction camps in the N.W.T. Much of this area is situated in permafrost regions or in locations where the water table is close to the ground surface. Irrigation with effluent under such conditions would cause a rapid saturation of the soil and the possibility of contamination of ground water and surrounding water bodies could become a problem.

2. INTRODUCTION

2.1 Nature and Scope of Study

This study examines the effect of land sewage disposal on subarctic vegetation, and, in particular, the impact of such disposal on areas which have been subjected to surface disturbances through the activities of man.

2.2 Relation to Proposed Pipeline Development

If the development of a pipeline down the Mackenzie Valley is undertaken, a large labor force will be required during construction, requiring a number of large transient work camps along the proposed route. Each of these camps will be faced with the problem of disposing of its domestic sewage. The land application of effluent may provide an inexpensive and effective method of sewage disposal. Also, secondary benefits might be derived from land irrigation. Sewage effluents contain important plant nutrients, notably nitrogen and phosphorus compounds, the availability of which is often limited in northern areas. Thus the application of nutrient-rich effluents to disturbed sites, such as cutlines, road sides and reclaimed borrow-pits, may assist in the revegetation and ultimate renovation of such areas.

3. CURRENT STATE OF KNOWLEDGE

The concept of waste disposal on land is not new. Irrigation of cropland with sewage wastes is a centuries-old practice. In recent years expected water shortages in many areas of the world have increased interest in the use of land for wastewater disposal.

Studies of land irrigation in forested areas have been reported in the literature, (Little et al., 1959; Sopper and Sagmuller, 1966; Sopper, 1971; Sopper and Kardos, 1973; and Urie, 1973). These studies, however, were conducted in temperate regions where severe climatic conditions, as experienced in northern Canada, were not a factor. Virtually nothing is known regarding land sewage irrigation in boreal, or arctic tundra communities.

4. STUDY AREAS

4.1 General Comments

Three areas were chosen for research purposes. Two are situated on disturbed sites within the boreal forest zone, one in a non-permafrost area near Fort Simpson, and the other in a location where underlying permafrost was present (Norman Wells). The third site is in a tundra dwarf shrub-heath community near Tuktoyaktuk. Only the two forest community sites will be discussed in this report, completion of the tundra irrigation study is scheduled for the fall of 1974 and will be reported at a later date.

4.2 Geographic Locations

4.2.1 Fort Simpson Site

The test area is situated on a seismic cut-line running in a northerly direction from the Mackenzie highway, between mile 304 and mile 305 (Figure 1).

4.2.2 Norman Wells Site

The study area is located on a cut-line approximately 0.8 of a mile northeast of the Gas Arctic test facilities at Norman Wells. Access is available from the road leading to the townsite quarry (Figure 1).

4.3 Climate

Both sites are included in Koppen's Dfc climatic classification or the subarctic classification of Brandon (1965). Such a climate is characterized by long, cold winter and short, cool summers, with some warm periods. Pertinent climatic data can be found in the Atmospheric Environment publication, Temperature and Precipitation. 1941-1970. The North - Y.T. and N.W.T.

4.4 Vegetation and Soils

4.4.1 Fort Simpson Site

Soil type was of the brunisolic order and the underlying parent material consisted of fine glacio-lacustrine sands. The site was imperfectly-drained and no permafrost was present.

Location of the area is within the Upper Mackenzie section of the boreal forest region (Rowe, 1972). The dominant forest cover was white spruce, *Picea glauca*, and aspen poplar, *Populus tremuloides*, with some intermixed black spruce, *Picea mariana*, and balsam poplar, *Populus balsamifera*. Composition of the shrub layer was wild rose, *Rosa acicularis*, willows *Salix* spp., and *Vaccinium* spp. Fireweed, *Epilobium angustifolium*, was the dominant species of the herb-grass layer. Sedges, *Cartex* spp., horsetails, *Equisetum* spp., wild strawberry, *Fragaria virginiana*, and bunchberry, *Cornus canadensis*, were also widespread.

Mosses and lichens were almost totally absent from the study area, although they formed an almost continuous mat on the undisturbed areas.

4.4.2 Norman Wells Site

Soils were poorly drained and consisted of a 30cm organic horizon underlain by a high-ice content, clayey till. At the time of vegetation sampling (mid-July), the active layer had an average thickness of approximately 35 cm.

The test site is situated in the transitional area between the Upper and Lower Mackenzie sections of the boreal forest zone (Rowe, 1972). The major aspect characterizing the separation of these two sections is the replacement of the *Populus* species, abundant in the Upper Mackenzie section, by white birch, *Betula papyrifera*, in the Lower section. Also, the prevalence of permafrost is more widespread in the Lower section and its impact upon the vegetation more pronounced.

Plots were established on a cut-line cleared through a mature black spruce community. Some scattered white spruce and tamarack, *Larix laricina*, were present. Alder, *Alnus crispa*, and white birch occurred in open areas. Dominant shrubs were willows, cinquefoil, *Potentilla fruticosa*, and wild rose. The dwarf shrub layer was composed of kinnickinnick, *Arctostaphylos rubra*; cowberry, *Vaccinium vitis-idaea*, and twinflower, *Linnaea borealis*. Major herbs were sedges, *Carex* spp.; horsetails, *Equisetum* spp.; and *Pyrola* spp. *Hylocomium splendens* and other feather mosses formed an almost continuous layer over the study area.

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1. SUMMARY

The intention of this investigation was to determine the overall effectiveness of extended aeration treatment plants operating at two Imperial Oil Limited drilling camps in the Mackenzie Delta area on the artificial islands IMMERK and ADGO-F28.

The observations and results of the investigation indicate the following:

1. There is a need for training programs for treatment plant operators in the North.

2. Raw sewage having a BOD_5 of 1000 to greater than 2000 mg/l can be expected at drilling camps.

3. More care is required in the sizing of treatment plants for camps in the North. Organic and hydraulic loadings require special consideration.

2. INTRODUCTION

The following report is supplementary to that prepared by Grainge et al, 1973.

The advent of oil and gas exploratory work in the Northwest Territories, accompanied by the possibility of large pipeline construction camps operating in the Mackenzie Valley necessitates a sound policy for domestic waste treatment in the North. One possible method for obtaining high sewage treatment efficiencies is by rapid biological decomposition of the waste by an activated sludge treatment process, such as an extended aeration treatment plant.

To date, the efficiency of extended aeration treatment plants operating in the Northwest Territories has not been assessed.

Through the assistance and cooperation of Imperial Oil Limited, extended aeration treatment plants on the IOL artificial islands, IMMERK and ADGO-F28, were evaluated with regard to plant performance and operational difficulties.

The two islands were constructed for the purpose of off-shore drilling, with the actual drilling operations in each location lasting for approximately three months.

During the investigation period an Environmental Protection Service employee was on site to assist in the operation of the plants.

The specific objectives of the project were to determine:

1. The characteristics of the raw waste to be treated,

2. The operation and maintenance requirements of the plants, and

3. The operational parameters necessary to reach a high level of treatment efficiency.

3. CURRENT STATE OF KNOWLEDGE

The activated sludge process has been used for domestic sewage treatment for several decades and its applications have been well documented. The capabilities of this process for obtaining high removals of BOD and suspended solids in treating domestic sewage has been proven many times over. However, the use of extended aeration treatment plants at work camps in the Northwest Territories is relatively new and their effectiveness as a means of treating camp wastes has not been extensively evaluated.

4. STUDY AREAS

The average treatment plants evaluated were manufactured by CLOW corporation. They were AER-O-FLO model 250 package plants of the type shown in Figure 1 having a design capacity of 9,433 l. of sewage per day. The treatment plants on IMMERK did not have effluent chlorination facilities.

4.1 IMMERK

The artificial island IMMERK was located east of Pelly Island in Mackenzie Bay and was constructed during 1972-73. The drilling camp was situated on a barge, owned by Northern Construction Co. Ltd. This barge was also used during the island construction phase.

During this investigation, the average population of IMMERK was approximately 50, with a sewage flow of approximately 11,330 l. per day. Water for washing and cooking was taken from the immediate vicinity of the camp and passed through a desalinization unit prior to use. Flush water for the toilets was taken directly from the surrounding area with no treatment before use. During part of the drilling period, the toilet flush water had a high silt and chloride content. The salinity of the water varied from 0 to 2.8%.

Two AER-O-FLO treatment plants were located in the lower portion of the barge at the aft end. One plant was on the starboard side and the other was on the port side. Figure 2 is a schematic diagram of the treatment plants locations. The two treatment plants were completely enclosed by the hull. The only access for servicing was through 61 by 91.5 cm. bolt-down hatches over the settling tanks. There was no shelter over these hatches. Raw sewage flowed by gravity from the washrooms and kitchen to the treatment plants and it was comminuted prior to entering the aeration compartments.

The owner and operator of the sewage treatment facilities was completely unfamiliar with the proper procedures for operating these plants.

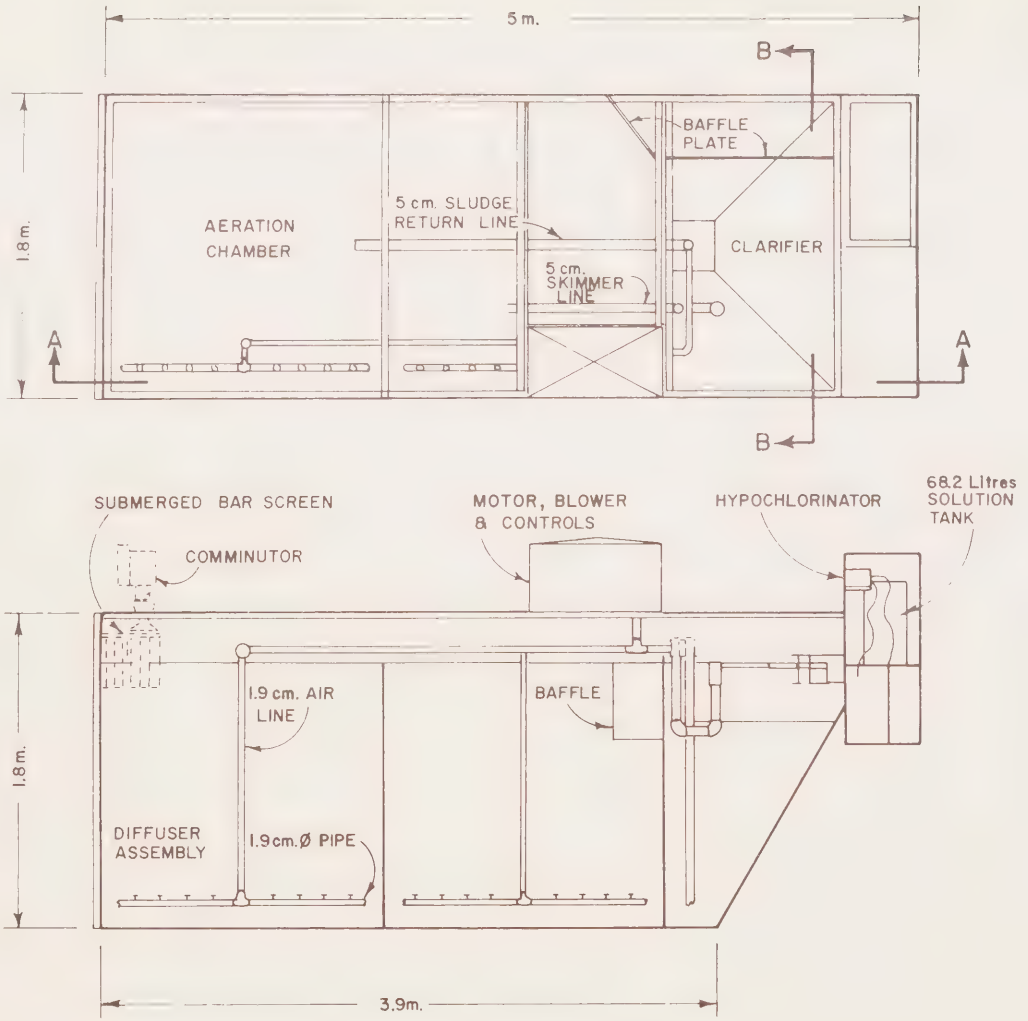
4.2 ADGO-F28

ADGO-F28 was located south of Garry Island in Mackenzie Bay. Construction of the island during August 1973 and drilling operations commenced during December, 1973. Water for domestic purposes was taken from the immediate vicinity of the island and it was chlorinated prior to use.

The AER-O-FLO treatment plant situated on the camp barge was purchased during August, 1973. The treatment plant was housed in a heated trailer and all parts of it were very accessible. Figure 3 is a diagram of the plant and raw sewage holding tank.

Sewage from the washroom and kitchen flowed by gravity to the holding tank which had a holding capacity of 90-140 litres before it was pumped to the plant.

MODEL 250 C AER-O-FLO PACKAGE SEWAGE TREATMENT PLANT



SECTION A-A

SECTION B-B

FIGURE 1

EXTENDED AERATION TREATMENT PLANTS IN BOTTOM OF BARGE (IMMERK)

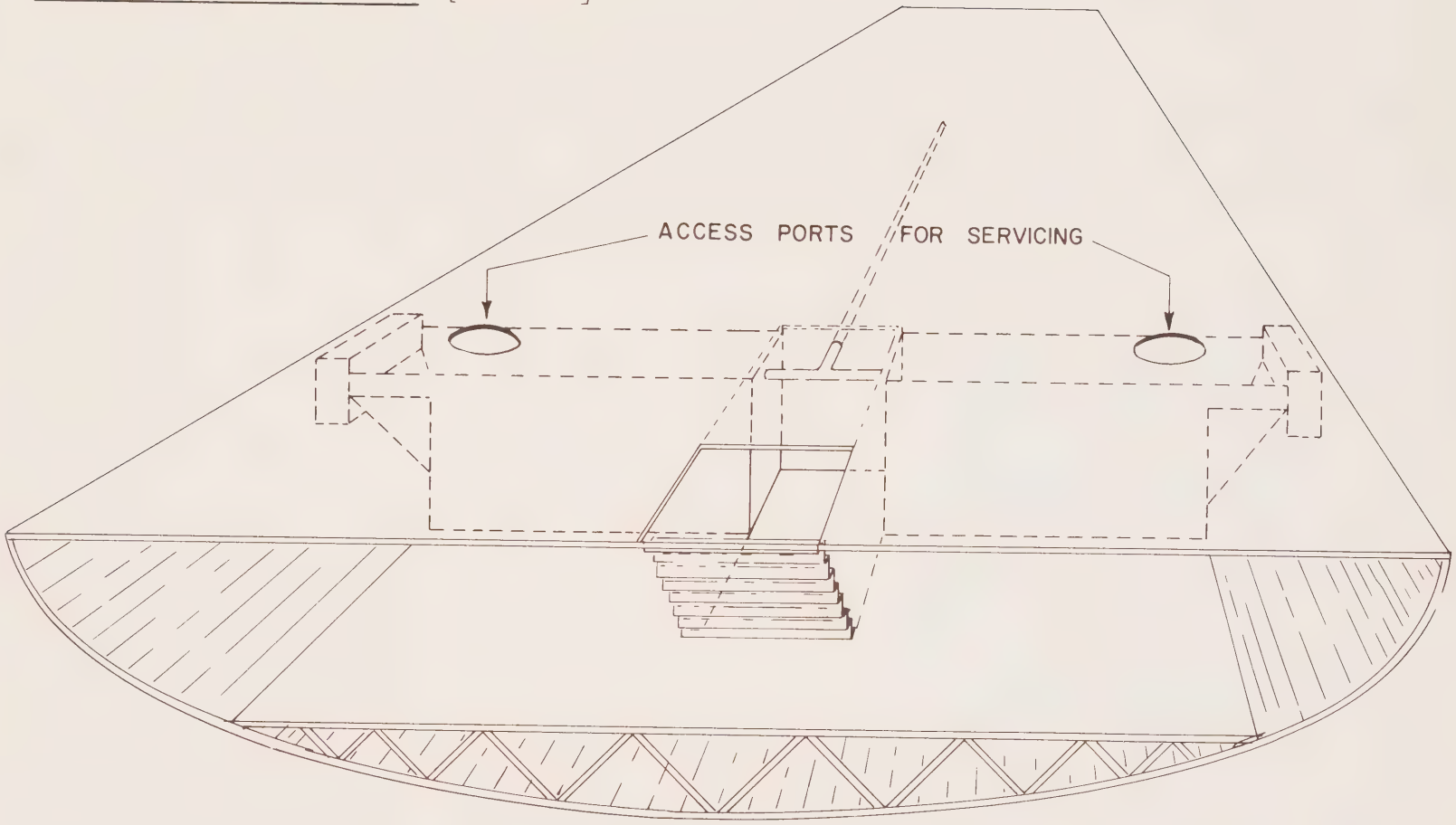


FIGURE 2

SEWAGE TREATMENT PLANT IN TRAILER HOUSING (ADGO F 28)

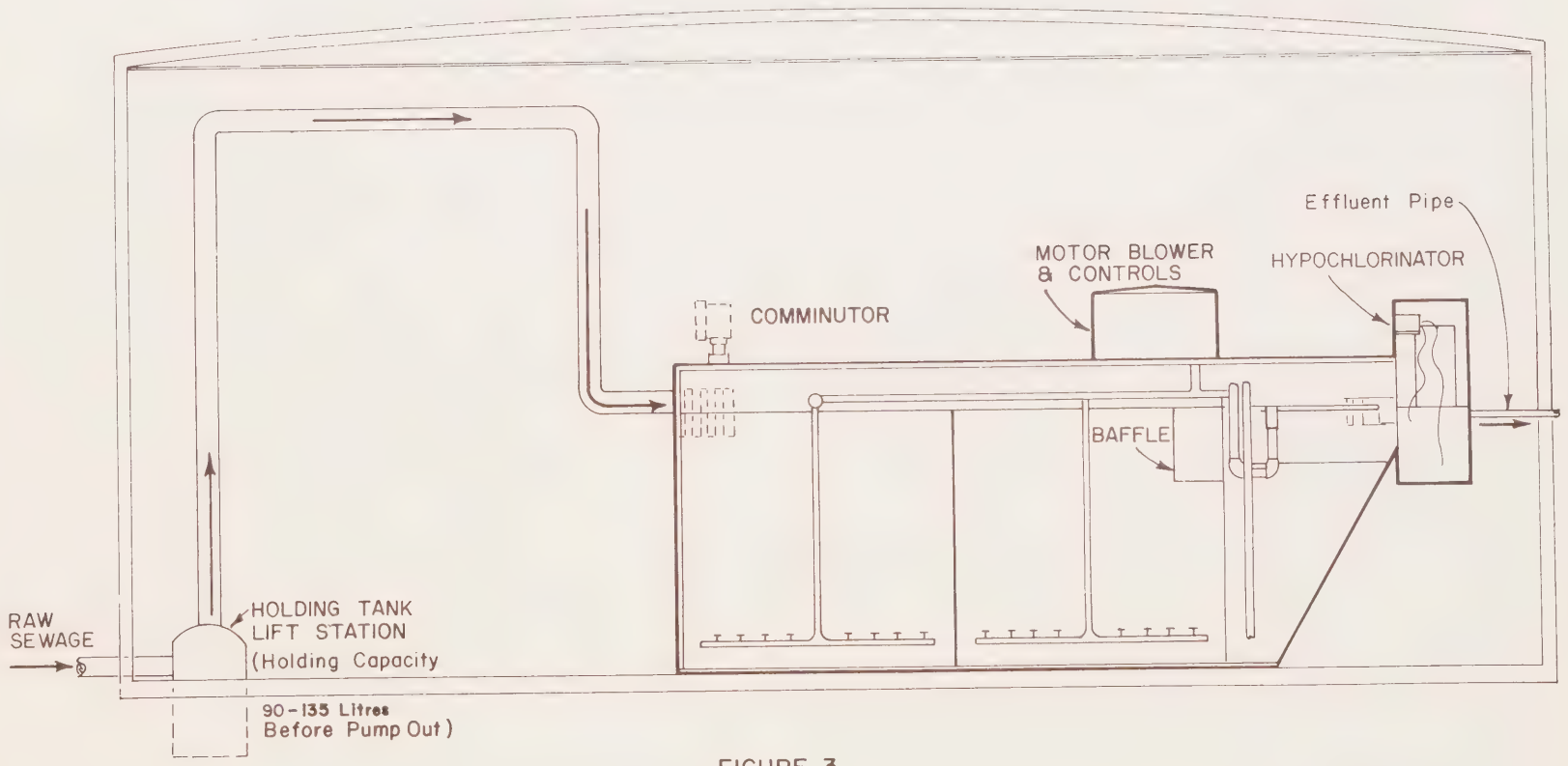


FIGURE 3

5. METHODS AND SOURCES OF DATA

A small number of samples were collected from the treatment plants at IMMERK because of inaccessibility to the various sections of the plants. A total of five "grab samples" were collected during the months of October and November, 1973.

At the beginning of January 1974, an extensive sampling program was started on the ADGO-F28 treatment plant. A number of 24-hour composite samples were collected of the raw sewage influent and treatment plant effluent. Daily routine tests and observations were also made on each stage of the plant with the overall objective of obtaining optimum treatment efficiency.

The samples for chemical analyses were frozen immediately after collection and forwarded to the Environmental Protection Service Laboratory in Edmonton for analyses. Most of the samples collected from the influent and effluent streams of the ADGO-F28 treatment plant were 24-hour composites. It is not known what effect freezing had on the various parameters.

The following analyses were carried out by the EPS Laboratory.

- BOD_5 (filtered & unfiltered)
- COD (filtered & unfiltered)
- Suspended Solids
- Volatile Suspended Solids
- Total Residue
- Fixed Residue
- pH
- Alkalinity
- Ammonia Nitrogen
- Nitrate Nitrogen
- Nitrite Nitrogen
- Total Phosphorus
- Organic Nitrogen
- Total Carbon (filtered & unfiltered)
- Organic Carbon (filtered & unfiltered)
- Inorganic Carbon (filtered & unfiltered)
- Hexane Extractables

All of the analyses were carried out in accordance with Standard Methods for the Examination of Water and Wastewater, 1971.

A series of bacteriological samples were also collected. The methods of analyses are given in Appendix B. Unfortunately, a number of the bacteriological samples froze before reaching the laboratory. The implications of this are discussed later in this report.

6. OBSERVATION AND RESULTS

6.1 IMMERK

The IMMERK treatment plants were inspected for the first time by an Environmental Protection Service employee on October 19 and 20, 1973. Observations made of the starboard plant were as follows:

1. Dissolved oxygen: 3-4 ppm (Hach kit).

2. Thirty minute settleable solids using 1000 ml. graduated cylinder: 0% (trace on bottom of cylinder). Supernatant was slightly murky. Evidence of food waste (corn, mushrooms, etc.) present.

3. Sludge return was translucent and rate appeared high.

4. Skimmer was not operating due to list in barge. A thin layer of scum was present on settling tank surface.

5. Color of aeration tank was light chocolate brown.

6. Diffusers appeared to be working well.

7. There was a large amount of rust build-up on the inside of the plant.

8. Blowers were running continuously.

9. A slight raw sewage odor was noticed.

When the port plant was inspected and sampled, the following observations were made:

1. Aeration tank appeared similar to starboard plant - light chocolate brown and evidence of food waste. A greater amount of rust was observed.

2. Diffusers were not working properly - bubbles and surface currents were not distributed evenly.

3. Dissolved Oxygen: 1 ppm. (Hach kit).

4. Settleable solids: 1 3/4 - 2% Supernatant was slightly murky.

5. Sludge return appeared translucent.

6. Skimmer was totally plugged.

7. Initial odor was similar to starboard plant but slightly stronger.

8. Blowers and sludge return were on continuous 24-hour operation.

In order to collect samples from the port plant, a black, fibrous mat on the surface of the settling tank had to be broken. This required about 5 kg. force. When the mat was broken, a thick, black fluid filled the hole along with clumps of black, spongy, floating material which was originally under the mat. A strong, septic, hydrogen sulfide and ammonia-like odor was noted.

One sample was taken from the settling tanks of the two plants. In each case the surface layer was avoided as much as possible. A third sample was collected, through the ice at the side of the barge, near the discharge of the starboard plant, at a depth of 2.5 m, which was 0.3 m above the sea bottom. A fourth sample was taken through the ice on the port side of the barge near the discharge of the port plant at a depth of 0.5 m. which was 15 cm. above the sea level.

No routine analyses were being carried out concerning operation of the treatment plants.

On November 30, 1973, a second sample was taken from the settling compartment of the starboard plant. The port plant was not in operation at that time. Table 1 gives the results of the analyses carried out on all the samples collected.

6.2 ADGO-F28

At the time of initial inspection, of the ADGO-F28 waste treatment facilities, on October 3, 1973, there were approximately 20 men in residence at the camp. A relatively strong sewage odor was noted in the vicinity of the treatment plant. The contents of the aeration and settling compartments were a dark grey color and a number of grease balls were floating in the aeration compartment. The air blowers were being operated on a fifteen minute on-off cycle with what appeared to be a very high sludge return rate. There was no equipment available for doing routine tests concerning the operational performance of the plant. The operator was unfamiliar with the proper operational procedure for the plant.

A grab sample was collected from the settling compartments at a 15 cm. depth. The results of the analyses of this sample and a sample taken of the chlorinated effluent on November 30, 1973 are given in Table 2.

The domestic water being used at the time of the October inspection had been hauled from Imperial Oil Limited's Bar C Camp in the Mackenzie Delta. When this supply was depleted, the camp population was reduced to 3 men for a period of

approximately one month. The camp population was increased to approximately 40 men during November. The domestic water supply was then taken directly from the area around the island. It was chlorinated before use.

Appendix A contains the results of the analyses carried out on the influent and effluent composite samples taken during the course of this investigation. Daily observations are also included in Appendix A. Monthly averages of the results are given in Table 3. Table 4 contains average percent removals of a number of the parameters measured.

Tables 5, 6, 7 and 8 give the bacteriological determinations of coliform bacteria, fecal coliform bacteria, fecal streptococci, and standard plate counts at 35°C and 20°C. The bacteriological samples were collected from the raw sewage influent, the treatment plant settling compartment and the chlorinated effluent.

TABLE I

SEWAGE ANALYSES OF SAMPLES TAKEN FROM EXTENDED AERATION TREATMENT PLANT
I.O.L. - IMMERK

	Starboard Plant Settling Compt. (Oct. 23)	(Nov. 30)	Port Plant Settling Compt. (Oct. 23)	Starboard Plant Outfall (Oct. 23)	Port Plant Outfall (Oct. 23)
BOD_5	675	5400	4050	225	166
BOD_5 (filtered)	-	232	-	-	-
COD	716	1000	41700	368	119
COD (filtered)	-	955	-	-	-
Suspended Solids	267	6452	72850	215	22
Volatile Suspended Solids	164	6140	66000	96	3
Total Residue					
Fixed Residue					
pH	7.6	6.9	6.5	7.6	8.0
Alkalinity as $CaCO_3$	532	576	1000	212	98
Ammonia Nitrogen	24	235	36	29	3.0
Nitrate Nitrogen	0.15	0.33	0.17	<0.10	0.11
Nitrite Nitrogen	<0.01	<0.01	<0.01	<0.01	<0.01
Total Phosphorus	0.23	20.0	106	7.33	0.10
Organic Nitrogen	25.8	27.5	213	19.5	11.0
Total Carbon	313	788	830	170	28
Total Carbon (filtered)	-	285	-	-	-
Organic Carbon	200	670	781	131	6
Organic Carbon (filtered)	-	191	-	-	-
Inorganic Carbon	113	118	49	39	22
Inorganic Carbon (filtered)	-	94	-	-	-
Oils & Crease					

NOTE: All constituents are in mg/l except pH which is in pH units.

TABLE 2
SEWAGE ANALYSES OF SAMPLES TAKEN FROM EXTENDED AERATION TREATMENT PLANT
I.O.L. - ADGO - F-28

	Settling Compt. (October 3/73)	Chlorinated Effluent (November 30/73
BOD_5	1100	652
BOD_5 (filtered)	-	396
COD	2284	1337
COD (filtered)	-	655
Suspended Solids	644	438
Volatile Suspended Solids	540	318
Total Residue		
Fixed Residue		
pH	7.5	7.6
Alkalinity as $CaCO_3$	626	661
Ammonia Nitrogen	100	95
Nitrate Nitrogen	0.19	0.33
Nitrite Nitrogen	0.01	0.05
Total Phosphorus	40	53.3
Organic Nitrogen	75	30
Total Carbon	847	530
Total Carbon (filtered)		310
Organic Carbon	681	417
Organic Carbon (filtered)		211
Inorganic Carbon	166	113
Inorganic Carbon (filtered)		99
Oils & Grease		

NOTE: All constituents are in mg/l except pH which is in pH units.

AVERAGES OF SEWAGE ANALYSES OF ADGO-F28 TREATMENT PLANT INFLUENT AND EFFLUENT

	INFLUENT JAN/74	INFLUENT FEB/74	EFFLUENT JAN/74	EFFLUENT FEB/74
BOD_5	2080	1750	413	383
BOD_5 (filtered)	670	543	265	223
COD	3154	2505	1164	978
COD (filtered)	1083	1363	592	523
Suspended Solids	1339	900	332	281
Volatile Suspended Solids	1083	720	219	210
Total Residue	2097	1921	1984	1658
Fixed Residue	954	863	1430	1130
pH	7.8	7.8	7.6	7.8
Alkalinity as $CaCO_3$	642	595	715	710
Ammonic Nitrogen	173	105	178	96
Nitrate Nitrogen	0.10	0.15	0.10	0.1
Nitrite Nitrogen	0.10	0.01	0.10	0.01
Total Phosphorus	37	41	36	37
Organic Nitrogen	110	40	74	47
Total Carbon	936	973	447	456
Total Carbon (filtered)	399	347	326	289
Organic Carbon	827	887	306	325
Organic Carbon (filtered)	295	264	179	159
Inorganic Carbon	109	86	141	131
Inorganic Carbon (filtered)	104	83	147	130
Oils & Grease	419	414	42	27
Average Flow (gallons/day)	1435	1413		

NOTE: All constituents are in mg/l except pH which is in pH units.
Influent Analyses of January 29/30 were not used in averaging values.

TABLE 4

AVERAGE REMOVALS IN ADGO-F28 TREATMENT PLANT

	JAN./74 (mg/l)	(%)	FEB./74 (mg/l)	(%)
BOD_5	1667	80	1367	78
BOD_5 (filtered)	405	60	320	59
COD	1990	60	1527	61
COD (filtered)	491	45	840	61
Suspended Solids	1007	75	619	69
Volatile Suspended Solids	864	80	510	71
Total Residue				
Fixed Residue				
pH				
Alkalinity as $CaCO_3$				
Ammonia Nitrogen				
Nitrate Nitrogen				
Nitrite Nitrogen				
Total Phosphorus				
Organic Nitrogen	36	33	0	0
Total Carbon	489	53	517	53
Total Carbon (filtered)	73	18	58	17
Organic Carbon	521	63	562	63
Organic Carbon (filtered)	116	39	105	40
Inorganic Carbon				
Inorganic Carbon (filtered)				
Oils & Grease	377	90	387	94

TABLE 5

BACTERIOLOGICAL RESULTS
ADGO-F28 EXTENDED AERATION SEWAGE TREATMENT PLANT
6 FEB. - 18 FEB.

Sample	Date	Coliform MF per 100 ml	Fecal Coliform MF per 100 ml	Fecal Streptococci MF per 100 ml	Standard Plate Counts per ml 35°C	Standard Plate Counts per ml 20°C
Incoming Sewage	6 February 74	4.8×10^6	3.9×10^5	3.0×10^3	1.2×10^5	1.7×10^5
	11 February 74	6.7×10^8	1.2×10^8	1.3×10^5	2.5×10^7	3.2×10^7
	15 February 74	3.5×10^9	3.4×10^7	4.2×10^3	6.5×10^7	5.7×10^7
	18 February 74	2.2×10^6	1.6×10^5	2.0×10^2	3.4×10^4	3.7×10^4
	Arithmetic Mean	1.0×10^9	3.9×10^7	3.4×10^4	2.2×10^7	2.2×10^7
Settling Tank	6 February 74	4.4×10^5	4.5×10^4	2.0×10^3	1.2×10^5	1.6×10^5
	11 February 74	1.5×10^8	1.4×10^7	2.2×10^4	7.4×10^7	1.4×10^8
	15 February 74	3.4×10^8	1.5×10^8	8.8×10^5	9.7×10^7	2.4×10^8
	18 February 74	1.2×10^7	6.1×10^5	1.5×10^5	5.9×10^7	7.8×10^7
	Arithmetic Mean	1.2×10^8	4.1×10^7	2.6×10^5	5.7×10^7	1.1×10^8
Final Effluent	6 February 74	1.7×10^6	1.2×10^5	4.3×10^3	5.2×10^5	7.0×10^5
	11 February 74	1.1×10^8	1.2×10^7	1.0×10^3	5.6×10^7	6.8×10^7
	15 February 74	8.7×10^6	1.4×10^5	3.2×10^3	2.5×10^6	9.3×10^6
	18 February 74	7.6×10^6	4.7×10^5	9.4×10^4	4.2×10^7	8.3×10^7
	Arithmetic Mean	3.2×10^7	3.2×10^6	2.6×10^6	2.5×10^7	4.0×10^7

Note: Samples received February 11, 1974 were the only unfrozen samples.

TABLE 6

COLIFORM % REDUCTIONS (ADGO-F28)

Date	Raw to Settling Tank	Settling Tank to Final Eff.	Raw to Final Eff.
Feb. 6/74	90.834	74.118*	65.584
11	77.612	26.267	83.582
15	90.286	97.442	97.514
18	81.667*	36.667	71.053*

* Increase in counts from location to location

TABLE 7

FECAL COLIFORM % REDUCTIONS (ADGO-F28)

Date	Raw to Settling Tank	Settling Tank to Final Eff.	Raw to Final Eff.
Feb. 6/74	88.462	62.500*	69.231
11	88.334	14.286	90.000
15	77.334*	99.907	99.588
18	73.771*	22.951	65.958*

* Increase in counts from location to location.

TABLE 8

STANDARD PLATE COUNTS AT 20°C % REDUCTION (ADGO-F28)

Date	Raw to Settling Tank	Settling Tank to Final Eff.	Raw to Final Eff.
Feb. 6/74	5.882	77.143*	75.414*
11	77.143*	51.429	52.941*
15	76.250*	96.125	83.684
18	99.952*	6.025*	99.955*

* Increase in counts from location to location.

7. DISCUSSION

7.1 IMMERK

The results show that the treatment plants were not operating efficiently. There were two reasons for this:

1. The operator of the treatment plants had no previous experience or training in proper operation of an extended aeration treatment plant.

2. The inaccessibility of the treatment plants on the barge made them virtually impossible to service to a degree where adequate treatment could be expected.

7.2 ADGO-F28

Most of the data collected for this report was obtained at ADGO-F28. The main reason for this was the accessibility to the treatment plant and to all the components making up the transporting systems to and from the plant.

The data collected show that the ADGO-F28 treatment plant was organically overloaded.

During the month of January, the average camp population was approximately 55 and during the sampling period in February it was approximately 50. The actual population could vary considerably from this, especially during crew changes.

Using these populations and the average influent loadings given in Table 3 the treatment plant would be required to treat the following average daily loadings:

	Jan. 1974	Feb. 1974=
BOD_5 (influent)	13 kg. (240 gm./man)	11 kg. (222 gm./man)
Suspended Solids (influent)	9 kg.	6 kg.

The average number of pounds of BOD_5 and suspended solids discharged in the effluent daily during January and February, 1974 were as follows:

	Jan. 1974	Feb. 1974
BOD_5 (effluent)	2.5 kg.	2.0 kg.
Suspended Solids (effluent)	1.8 kg.	1.5 kg.

The AER-O-FLO package treatment plant was actually designed for an average BOD_5 loading of approximately 3 kg. per day. Therefore, the treatment plant was originally overloaded by 3.6 to 4.4 times.

Martin and Schmidt, 1973, have suggested a BOD_5 design parameter of 1 kg/day per man for offshore drilling in the United States. This is approximately two-fifths of the loading experienced on ADGO-F28.

Table 9 gives some raw sewage characteristics experienced in Alaska (Clark et al, 1971). Although the number of samples is limited, the results do indicate that a wide range of values can be expected.

Table 4 shows that BOD_5 removals of 80% were being accomplished in the ADGO-F28 treatment plant. This percentage of removal is somewhat misleading because the effluent BOD_5 was still exceedingly high. These results indicate that a treatment plant serving a drilling camp should provide BOD_5 removals of greater than 98% if an acceptable effluent is to be discharged to the surrounding environment. It would be very difficult for a conventional extended aeration treatment plant to meet this critesion.

Table 4 shows that the per cent organic carbon conversion was only 63%, compared to an impressive 80% removal of BOD_5.

It may be possible, however, to reduce the loading on a treatment plant operating under these conditions. It should be noted that the ADGO-F28 raw sewage influent contained a large amount of hexane extractables (oils and greases). It is believed that this contributed substantially to the loading on the plant.

Figure 4 shows graphically the relationship between the oils and greases (hexane extractables) and COD, BOD_5, volatile suspended solids, and organic carbon of influent samples. The hexane extractables vary according to the other four parameters.

Figure 5 compares graphically the hexane extractables with the filtered-residue BOD_5, COD and organic carbon of the influent samples. The majority of the oils and greases would have been filtered out and therefore any loadings to the plant contributed by this fraction would be reflected in the results of the filtered samples. Figure 5 does in fact show a correlation between the oils and greases and the portion of the BOD_5, COD and organic carbon that was filtered out.

The removal of the hexane extractables from the influent raw sewage stream could reduce the organic loading on the plant substantially, and in turn result in a higher quality effluent being discharged.

In an attempt to reach as high a treatment efficiency as possible, under the existing conditions, the air blower was put on continuous operation at maximum capacity in order to reach a dissolved oxygen level of 1-3 mg/l in the aeration compartment. The organic loading was too great and no residual dissolved oxygen could be maintained. This is recorded in the routine testing results in Appendix A. An attempt was also made to add extra oxygen by the addition of hydrogen peroxide (H_2O_2). This proved to be of no value. The H_2O_2 was utilized almost immediately after addition, indicating a very high oxygen demand. The H_2O_2 additions and results are given in Appendix A, page 37.

Due to the inability to maintain an oxygen level in the aeration compartment an aerobic biological floc could not be supported. This is also recorded in the routine daily testing records in Appendix A. The return sludge from the settling compartment was continually anaerobic and had poor settling characteristics.

The deficiency of oxygen throughout the treatment plant is well reflected in the nitrogenous compounds in the samples analysed. There was virtually no conversion of organic and ammonia nitrogen to nitrite or nitrate nitrogen.

During January there was a decrease in organic nitrogen content in passing through the plant (see Table 3, page 15) accompanied by a slight increase in ammonia nitrogen. The organic carbon to organic nitrogen ratios of the influent and effluent were 7.5 and 4.1 respectively. Because of these variations it appears that the organic nitrogen was being converted to ammonia nitrogen, with ammonia nitrogen given off to the atmosphere.

The influent and effluent results for February, on the other hand, show an increase in organic nitrogen and a decrease in ammonia nitrogen. The organic carbon to organic nitrogen ratios for the influent and effluent were 22 and 6.8 respectively. The C:N ratio of 22 is at the approximate maximum limit for removal of organic nitrogen by the organisms. This would explain the increase in organic nitrogen through the plant. The organisms were actually utilizing the available nitrogen for cell syntheses thus resulting in the higher values in the effluent.

The average removals of BOD_5, COD and carbons (Table 4) show that the largest percentage of removals was in the filterable portion of the samples. At the same time there was a high reduction in oils and greases, indicating

once again that the oils and greases were probably contributing substantially to the organic loading on the plant.

The reductions of total carbon were probably due to gaseous carbon compounds given off to the atmosphere.

Graphical representation of effluent concentration of BOD_5, COD and organic carbon are given in Figure 6. The variation of these parameters in the effluent stream were not as pronounced as those in the influent stream. The effluent COD curve (Figure 4), however, does show the general trend of influent COD. The BOD_5 and organic carbon curves show relatively constant concentrations. One reason for this buffering trend would be the dilution effect and thorough mixing in the treatment plant.

As can be seen by the influent results the waste entering the plant was not consistent in BOD, COD, organic carbon, volatile suspended solids and oils and greases. These parameters vary considerably from day to day as shown in Figure 4. This would undoubtedly create problems in efficient treatment, even if the plant was sized properly.

The anaerobic conditions combined with the varying organic loading made it impossible to maintain any kind of a consistent mixed liquor suspended solids concentration or sludge volume index. This is shown in Appendix A. It is interesting to note, however, that the SVI's were still in the acceptable range for proper operation of extended aeration treatment plants, during most of the time, even though the other operating parameters, such as dissolved oxygen, were not in the range recommended.

Conclusions from the bacteriological results cannot be made as freely as one would wish. The results, although possibly indicative, must be considered unreliable as all the samples were frozen, except for those received on February 11. Freezing of samples usually has the effect of partial sterilization and this sterilization effect is not consistent. Factors affecting the population would be temperature of freezing, speed of freezing, organic and particulate make up of the sample and quantities and types of population within the sample.

All of the data are outlined in Table 5. Although the samples were frozen, the results do reveal extremely high populations of coliforms, fecal coliforms, fecal streptococci and total heterotrophic bacteria. The numbers would indicate the likely passage of pathogenic organisms into the environment showing the inadequacy of the chlorination system. The high numbers of heterotrophs throughout the system probably reflects a high organic loading in the plant.

Tables 6, 7 and 8 show what was hoped would be the bacterial reduction throughout the system. In fact, they very often show increased numbers, particularly in the settling tank and frequently between the raw and final effluent. This indicates that the settling tank is in fact functioning very well as a growth chamber. Chlorination of the effluent is obviously having little or no effect on the bacteriological population. This is probably due to the high organic content in the effluent.

7.3 General

The observations and results to date show that if the treatment plants investigated are to be used for future camps of a similar nature, a number of changes will have to be made if a good quality effluent is to be expected. Suggested changes for the treatment plants at IMMERK are as follows:

1. The hatch in the deck above the plants should be enlarged so that all diffuser valves and lines, the sludge return lines, and the effluent troughs are accessible by hand, and so that all sides and corners of the settling tank and aeration tank are accessible for cleaning.

2. An insulated, heated, ventilated and lit shelter, large enough for an operator to stand in and have working access to the plants, should be constructed above the hatches.

These changes require major alterations to the present system, but they are necessary if the treatment plants are to serve the purpose for which they were designed.

It is recommended that additional work be carried out on the treatment plant that was situated on ADGO-F28 to determine what size of camp it is suited for.

Another very important point which must be kept in mind when considering the use of extended aeration treatment plants at northern camps is that these plants require a trained and conscientious operator whose prime responsibility is to maintain an efficient operating plant. Too often these plants are operated by the camp maintenance man, who has had no training in the routine tests which must be carried out and in the overall theory of the operation of the plant. This appears to have been the case at IMMERK. IMMERK, however, is not the only treatment plant being operated by an untrained operator. Table 10 and Fig. 7 give effluent results of extended aeration treatment plants operating in Alaska and Manitoba, respectively. The operators of all the plants discharging an acceptable effluent are conscientious about their work. The operator of all of the plants in Manitoba, meeting the Federal Facility BOD objectives, have attended an operator training program.

Although it was virtually impossible, under the conditions, to treat the camp sewage at IMMERK and ADGO-F28 to an acceptable degree, valuable information was obtained concerning the chemical and bacteriological characteristics of raw sewage that could require treatment at northern camps.

The raw waste at ADGO-F28 appeared to be biologically treatable with respect to pH, alkalinity, nitrogen, phosphorus and organic carbon. However, many more data are required concerning the characterization of camp wastes before general recommendations can be made regarding a treatment plant size for a given installation.

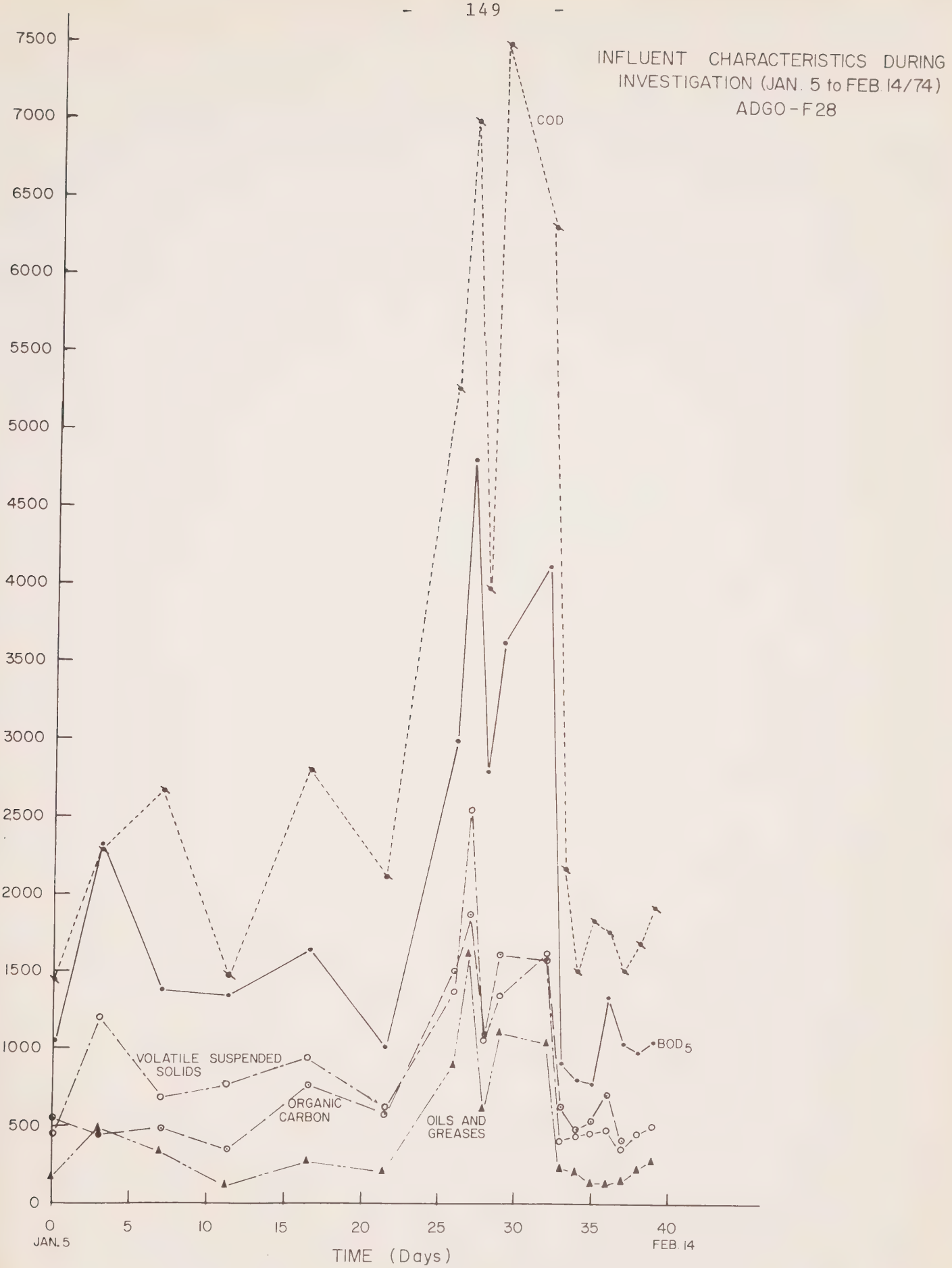

INFLUENT CHARACTERISTICS DURING
INVESTIGATION (JAN. 5 to FEB. 14/74)
ADGO - F28
COD
BOD5
VOLATILE SUSPENDED SOLIDS
ORGANIC CARBON
OILS AND GREASES
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
JAN. 5
FEB. 14
TIME (Days)

FIGURE 4

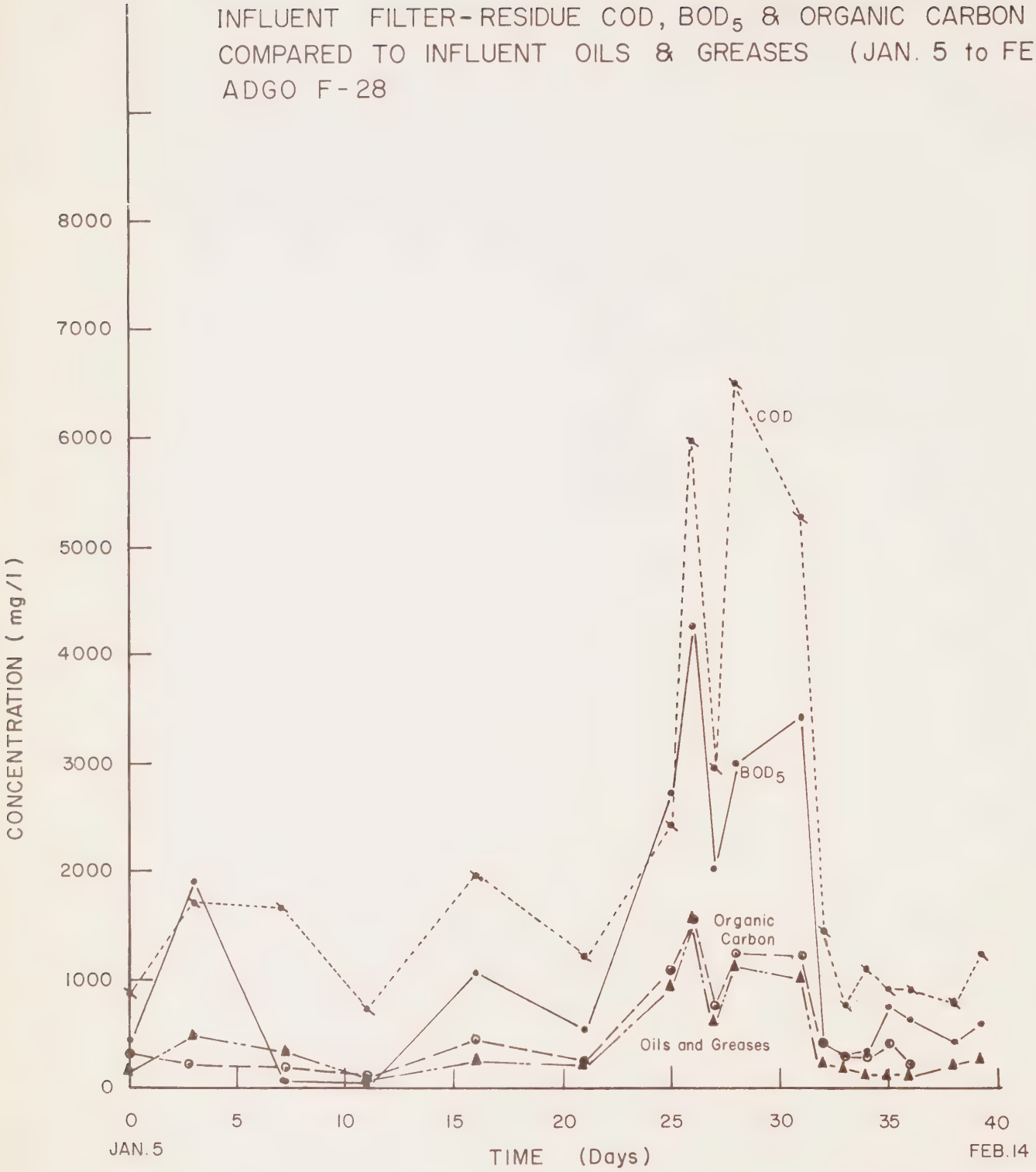

INFLUENT FILTER-RESIDUE COD, BOD5 & ORGANIC CARBON
COMPARED TO INFLUENT OILS & GREASES (JAN. 5 to FEB. 14/74)
ADGO F-28
CONCENTRATION (mg/l)
8000
7000
6000
5000
4000
3000
2000
1000
0
COD
BOD5
Organic Carbon
Oils and Greases
0
5
10
15
20
25
30
35
40
JAN. 5
TIME (Days)
FEB. 14

FIGURE 5

EFFLUENT COD, BOD_5 and ORGANIC CARBON VARIATIONS
(JAN. 6 to FEB. 11/74) ADGO-F 28

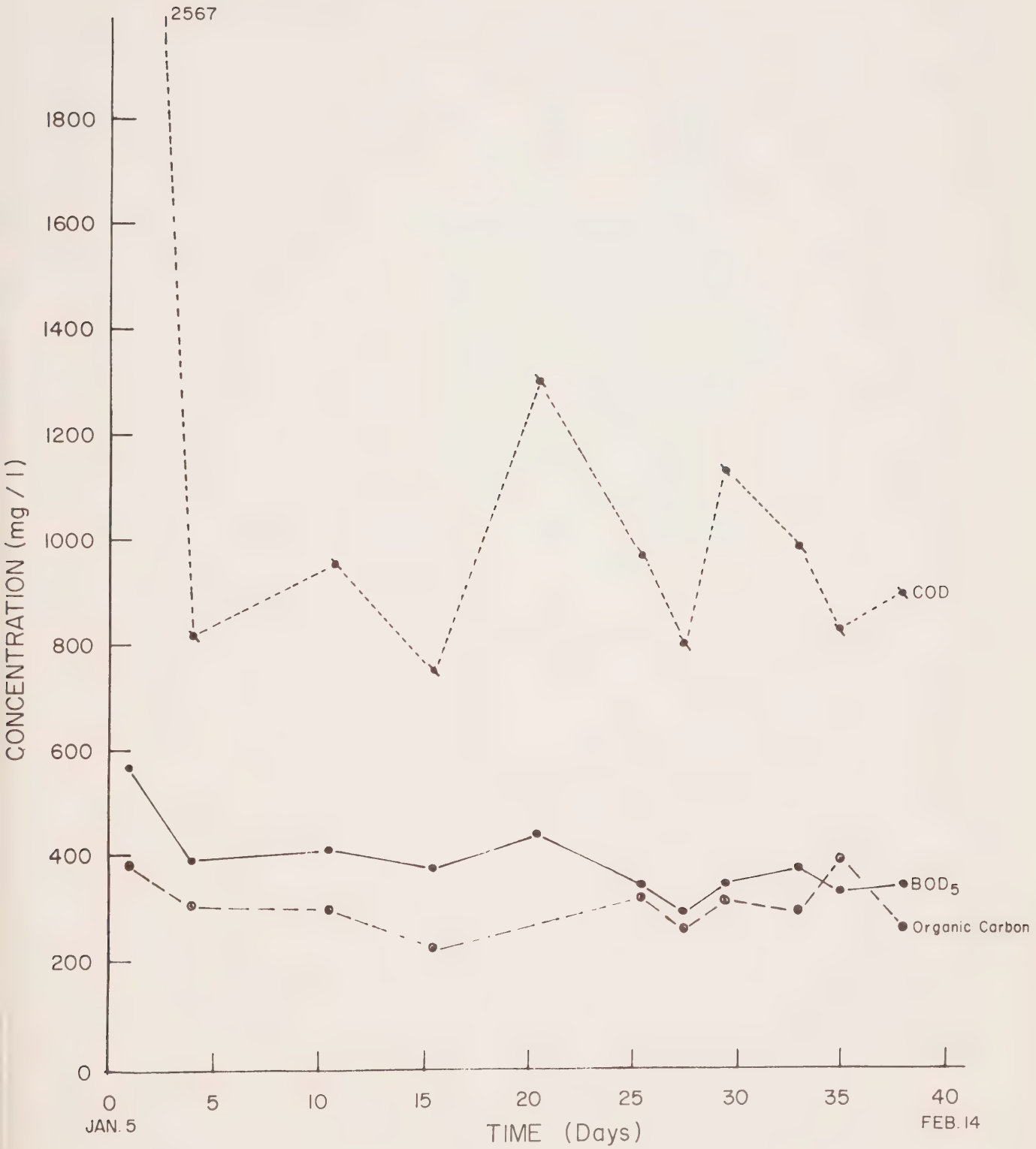


FIGURE 6

TABLE 9

(after Clark et al, 1971)

NORTH SLOPE RAW SEWAGE CHARACTERISTICS

Location	Date	Population	BOD	COD	TS	SS
Toolik	7/16/70*	12	484	842	894	387
	8/20/70*	12	380	2440	2790	330
	9/30/70*	9	-	1605	1298	228
	3/17/71*	7	-	7610	-	-
	3/22/71*	7	-	3260	-	-
Deadhorse	8/20/70*	10	740	2000	2024	816
	9/16/70*	6	-	842	-	811
Mikkelson (All wastes except toilet)	4/13/71**	50	-	550	-	-
(Toilet Wastes)	4/21/71	50	-	460[1]	-	-
Galbraith	7/16/70*	15	500-1100	3600	3316	2788
	8/30/70*	10	-	232	582	256
Prudhoe	8/20/70*	85	7830	2510	3154	1547
(Average of 7 days of composites in March 1971)**		75	600	1150	-	1500

* Grab samples from mixed surge tanks

** Composite samples taken with composite sampler on basis of frequency but not flow matching

1 Sampled by others

TABLE 10

(after Clark et al, 1971)

NORTH SLOPE SEWAGE TREATMENT
PLANT EFFLUENT CHARACTERISTICS

System	Date	BOD	COD	SS
Galbraith	9/16/70	-	696	291
	7/16/70	33	-	68
	9/01/70	28	-	15
	9/30/70	-	113	28
Happy Valley	9/30/70	0	324	147
Prudhoe	7/30/70	180	364	34
	8/20/70	153	371	106
	9/16/70	-	1167	1049
	3/12/71	40	170	68

8. CONCLUSION

1. The sewage treatment plants on IMMERK will not operate efficiently until alterations are made so that the plants can be serviced.

2. The ADGO-F28 treatment plant was organically overloaded.

3. The organic loading of the influent raw sewage to the ADGO-F28 treatment plant was approximately 4 times that for which the treatment plant was designed.

4. The effluents of the IMMERK and ADGO-F28 sewage treatment plants were of very poor quality and pathogenic organisms and viruses were probably being passed to the receiving waters.

5. The chlorinator on the ADGO-F28 treatment plant was having little or no effect on destroying pathogenic bacteria in the effluent.

9. IMPLICATIONS AND RECOMMENDATIONS

9.1 Pipeline Construction Camps

The potential use of extended aeration treatment plants at pipeline construction camps must be recognized and certain precautions must be taken before allowing a camp site to use this type of treatment. It is essential that conditions and stipulations, as listed below, accompany the granting of a permit to install an extended aeration treatment plant, or for that matter, any type of treatment plant at a pipeline construction camp.

1. A best estimate of the chemical, physical and bacteriological characteristics of waste to be treated should be made. This estimate should be based upon analyses of raw sewage from existing camps of a similar nature.

2. The treatment plant and all of its components including the influent and effluent lines must be very accessible to inspection and servicing.

3. Each treatment plant must be accompanied by a small laboratory, able to carry out routine daily analyses.

4. A trained and conscientious operator must be in charge of each plant. The prime responsibility of the operator should be the proper operation of the plant.

5. Samples of the plant effluent should be collected on a regular basis of at least once every two weeks and sent to an independent laboratory for routine sewage analyses.

6. An acceptable program for sludge wasting and a means of sludge disposal must be specified by the contractor.

9.2 General Recommendations Concerning Package Extended Aeration Treatment Plants

The extended aeration process is well known for its inability to accept shock loadings (hydraulic and/or inorganic) while maintaining a high treatment efficiency. These shock loadings are even more critical in small extended aeration plants. It is therefore recommended that a large holding tank, capable of damping out peak flows and making up for low flows of incoming raw sewage, be installed. A pump with a capacity approximately the same as the average daily flow should then be used to pump raw sewage from the holding tank to the treatment plant, at a constant rate.

In addition the oils and greases should be separated and incinerated from the raw sewage.

The following are recommendations for proper day to day operation of extended aeration treatment plants at pipeline construction camps:

1. The following maintenance equipment should be available.

   a. Scraper for tanks
   b. Surface skimming net
   c. Dissolved oxygen test kit or dissolved oxygen meter
   d. 1000 ml graduated cylinder for 30 minute settling test
   e. Spare parts for blowers and comminutor as recommended by manufacturers

2. A routine maintenance program should be carried out which would include the following.

   Daily

   a. Remove floating material in settling tank with skimmer.

   b. Ensure that all mechanical and electrical equipment are functioning properly.

   c. Measure dissolved oxygen and settleable solids in aeration tank ensuring a D.O. of 1.0 to 3.0 mg/l.

   d. Observe color of mixed liquor, color of sludge return, clarity in settling tank, and odor in plant.

   e. Adjust diffuser valves, sludge return rate, and timers according to results from above tests and observations.

   f. Calculate the sludge volume index according to:

$$\frac{\text{30 minute settling tank (\%)} \times 10{,}000}{\text{suspended solids (mg/l)}}$$

   and maintain at approx. 100 by appropriate wasting.

   Weekly

   a. Scrape sides and sloping bottom of settling tank (daily until plant is mature).

   b. Clean out comminutor (more often if necessary).

   c. Clean sidewalls and troughs of all accumulation of grease, scum and solids.

   d. Check oil in blower gear box.

Other

a. Grease comminutor bearings every two weeks.

b. Change oil in comminutor gear housing once per month.

c. Change gear case oil of blowers every 2000 hours.

d. Lubricate blower shaft bearings periodically.

e. Sharpen or replace comminutor blades when dull.

3. Sludge wasting should take place on a regular basis depending on the specific conditions the plant is operating under.

4. The operator of the plants should be allowed an average of at least one hour each day to service the plant properly.

5. A daily logbook should be kept indicating results of tests, observations and maintenance work done.

10. NEED FOR FURTHER STUDIES

The high organic loadings observed in this investigation indicate that there is a need for further work in this area to determine the chemical, physical and bacteriological characteristics of raw sewage at northern work camps. A detailed examination should be made to determine the daily organic and hydraulic loadings and from where they originate, in a work camp. Characteristics of the wastes coming from the camp kitchen, the washroom and the laundry room should be determined. This investigation would have to be carried out at a number of different types of camps to compare sewage loading characteristics to the camp function.

11. REFERENCES

Clark, S.E., A.J. Alter, J.W. Scribner, H.J. Coutts, C.D. Christianson and W.T. McFall; 1971. Alaskan Industry Experience in Arctic Sewage Treatment; Environ. Protect. Agency Water Quality Office, Northwest Reg.; Alaska Water Lab., College, Alaska; Presented at 26th Purdue Ind. Waste Conf., Purdue Univ., Lafayette, Indianna.

Grainge, J.W., J.W. Shaw, J. Greenwood; 1973. Factors Affecting the Design and Operation of Activated Sludge Plants for Wastewater Treatment for Northern Work Camps; in Management of Waste from Arctic and Sub-Arctic Work Camps by Grainge, J.W., R. Edwards, K. Heuchert, and J.W. Shaw; Rep. 73-19 Environ.-Soc. Comm., N. Pipeline, Task Force on N. Oil Develop., Dep. Indian N. Aff. Ottawa.

Martin, J.C. and R.K. Schmidt; 1973. Domestic Waste Treatment in the Offshore Environment; U.S. Army Corps of Eng. and Ecodyne Corp.; Presented at Fifth Annu. Offshore Technol. Conf., Houston, Texas, Paper No. OTC 1737.

Standard Methods for the Examination of Water and Wastewater; 1971. APHA, AWWA, WPCF, Publ. Amer. Public Health Ass., New York, NY, 13th Ed.

WASTE IMPOUNDING EMBANKMENTS IN PERMAFROST REGIONS:

THE OXIDATION POND EMBANKMENT, INUVIK, N.W.T.

by

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1. SUMMARY

In permafrost regions, thaw bulbs exist beneath those masses of water which maintain a mean annual temperature above the freezing point of water. Because many permafrost soils are unstable when thawed, the creation of such thaw bulbs may create instability or seepage problems for embankments impounding water. One possible solution to this problem, constructing dykes utilizing non-cohesive, self-healing fill materials, is not acceptable for the containment of waste water because of the associated environmentally-damaging high seepage rates. Simple time-independent, steady-state calculations simulating the thermal regime in the vicinity of an embankment impounding waste water indicate that, in the higher latitudes at least, it should be possible to maintain a frozen core within the embankment, thus minimizing the problems related to instability and seepage.

A field site adjacent to the existing sewage lagoon at Inuvik, N.W.T., has been set up to monitor the thermal regime within and beneath the lagoon embankment. Preliminary data indicate that, at the start of winter, an unfrozen zone exists within the lower portions of the gravel embankment and extends a metre or more into the underlying foundation silts. This zone may be part of a deep active layer and/or be created by heat transported by water seepage. To check these conjectures it is necessary to continue monitoring the thermal regime for at least one full temperature cycle, that is, one year, and, concurrently, to use a time-dependent heat conduction model to attempt to make a quantitative simulation of the processes at work. Such a model may eventually be used as a design tool for embankments in the North.

2. INTRODUCTION

Accompanying the rapid development of the Canadian North there is a need for sound waste management for both permanent and transient communities. In the past, oxidation ponds have provided satisfactory treatment for domestic wastes at a number of communities in western and northern Canada. Because of the low-cost, dependable treatment capabilities and ease of operation, such systems are likely to be an important method of waste treatment in the North for many years in the future.

In permafrost regions, bodies of surface water create an appreciable perturbation in the ground thermal regime. In particular, thaw bulbs exist beneath those water masses which maintain a mean annual temperature above the freezing point. Since many permafrost soils are unstable when thawed, the creation of thaw bulbs beneath and adjacent to impounded water may create structural and seepage problems for the containing embankments.

The structural problems are essentially twofold. Firstly, the differential settlement created by uneven consolidation of the underlying thawing soil tends to produce cracks and fissures in the embankment above. Secondly, as the thaw front advances within a high-ice-content soil, relatively large volumes of water may be released which, unless allowed to escape, could result in the generation of excess pore-water pressures. Such a situation may lead to a drastic reduction in soil shear-strength in the thawing zone and contribute to the danger of catastrophic embankment failures.

In addition to requirements of structural stability, waste impounding embankments must be impermeable to ensure the necessary protection of the environment.

Ideally, data relevant to the performance of a newly constructed embankment is desirable, particularly in regard to stability considerations. Unfortunately, no suitable site is currently available, although a number of comprehensive lagoon systems are scheduled for construction in the near future. With this in mind, the field work for the overall project was separated into two stages: firstly, an examination of an existing embankment to determine the long-term state of such a structure; secondly, the monitoring of a site immediately before, during and after construction of a lagoon. Two possible locations for work on the latter stage are Norman Wells and Inuvik, N.W.T., where lagoon systems are scheduled for construction to begin in 1974 and 1975, respectively. To implement the first stage of the project, the embankment of the existing lagoon at Inuvik, N.W.T., was selected for study.

The object of this study is to observe the thermal regime within and adjacent to the lagoon embankment which, apparently, has performed adequately for almost twenty years. Theoretical heat flow calculations will be performed concurrently with the field studies to attempt to gain a quantitative understanding of the processes at work at this site.

3. RESUME OF CURRENT STATE OF KNOWLEDGE

When considering construction practices in permafrost regions, it is convenient to consider three general approaches if the foundation conditions indicate that normal temperate zone techniques are not applicable.

The first approach consists of appropriate modification to the foundation conditions prior to construction to ensure stability. The second approach allows, as part of the design, the occurrence of thermal degradation and associated settlement. Finally, the third approach encourages stability by the maintenance of the existing thermal regime.

In the discontinuous permafrost zone one of the former two approaches, or a combination of both, is generally favoured, since relatively minor thermal disturbances are generally sufficient to initiate the thawing processes in these regions. In northern Manitoba, for example, reservoir dykes have been constructed using non-cohesive, self-healing fill materials. (Johnston, 1969; MacPherson et al., 1970). Such soils allow limited differential movement and minor foundation failures without severe fissuring. Further, since non-cohesive soils typically exhibit high permeabilities, excess pore-water pressures are rapidly dissipated, a process which is further encouraged at the above-mentioned sites by the inclusion of sand drains beneath the dykes. Naturally, the significant seepage rate associated with such permeable embankments contributes to the foundation thawing process through the sensible heat transported by the water. Occasional remedial work is usually necessary and entails the placement of extra fill materials to maintain the design freeboard.

The final approach is generally reserved for those areas where the mean soil temperatures are significantly below the freezing point. In these cases the permafrost may be allowed to aggrade within the core of the dam, or freezing may be actively encouraged by the use of cooling pipes through which the cold winter air, or even a refrigerant, is circulated. (Bogoslovskiy et al., 1963). In particular, the thermal regime of a dam of the more economical, passive design has recently been reported. (Fulwider, 1973). This dam, the Crescent Lake Dam, is an earthfill embankment constructed in 1952 near Thule Air Base, Greenland, (mean annual air temperature approximately $-12^{\circ}C$), to impound a water supply for the base. Temperature readings collected between 1952 and 1959 indicated that the central part of the embankment remained frozen throughout the year, creating an impervious core section. However, similar readings from mine tailings pond dykes constructed of crushed rock, in Yellowknife, N.W.T., (mean annual air temperature approximately $-5^{\circ}C$), showed the existence of a thawed zone through the dykes for the majority of the year (Roy et al., 1973).

No detailed simulations of the thermal regime within a dyke constructed over permafrost are available in the literature. The only available theoretical work is a method developed for estimating the rates of thaw and associated settlement based on simple analytical approximations in heat conduction theory and which is strictly applicable only when sensible heat transported by seepage completely dominates the thawing process (Brown and Johnston, 1970).

4. STUDY AREA

The embankment studied in the field investigations impounds the lagoon which services the town of Inuvik, N.W.T. (68^{o} 18' N, 133^{o} 29' W). The town is located in the east-central part of the Mackenzie Delta, the physical geography of which has been described by Mackay (1963). The area experiences a tempered arctic climate with a mean annual temperature and precipitation of approximately -9^{o}C and 28 cm, respectively.

The Inuvik lagoon consists of a strip of water approximately 910 m x 250 m, averaging a depth of 1.2 m, lying to the north-west of the town-site and adjacent to the east channel of the Mackenzie River (Figure 1).

5. METHODS AND SOURCES OF DATA

5.1 The Field Site

Near the end of October 1973, thermal probes were emplaced and representative soil samples obtained.

Three holes were drilled through the lagoon embankment to a depth of 12 m for probes II, III and IV and one hole 61 m deep was advanced 3.5 m from the downstream edge of the embankment for probe V.

The cross-section of the embankment at the study-site and the location of the bore-holes are shown in Figure 2. The depths and relative positions of the temperature stations are indicated in Figure 3. A further probe was also included, labelled I in Figures 2 and 3, to obtain temperature data from the upstream surface of the embankment and along the bottom of the lagoon. In total, 44 temperature stations were employed.

5.2 The Instruments

Probes II, III and IV consist of Atkins PR 99-3 thermistors installed inside 2.54 cm diameter p.v.c. tubing filled with zonolite. To facilitate transportation and ease of handling, each probe was supplied in three sections with couplings fitted so that the probes could be finally assembled on site before insertion into the bore-holes. The two remaining probes consist of similar thermistors attached to a flexible p.v.c. cable reinforced by steel bracing wires.

Leads from the probes were channelled to termination boxes on the sides of the embankment. A meter may be connected to these boxes, each temperature station selected in turn, and readings recorded weekly to the nearest 0.3 ^{o}C.

5.3 The Samples

The holes were drilled using a Nodwell mounted Mayhew 100 drill-rig and variations of soil and groundwater conditions were noted. Representative samples of the subsoils were taken at intervals by pushing a 5 cm diameter split-spoon or 7.5 cm diameter, thick-walled Shelby tubes into the permafrost. Densities and moisture contents of these samples were determined in Inuvik. Samples of the 61 m deep test-hole consisted primarily of disturbed air-returned material.

The soil samples recovered from the drilling operations were subjected to standard laboratory classification procedures, including particle size distribution by sieve analysis and hydrometer tests, and Atterberg index property determinations. Moisture contents were obtained for all samples. Wet density, dry density and ice-content were obtained for the permafrost samples.

5.4 Mathematical Modelling

Initial numerical and analytical calculations have been performed to simulate the average thermal conditions in the vicinity of the lagoon edge. These calculations are of the steady-state variety and, consequently, they do not include any transient behaviour. Further, because of insufficient data from the field at this stage, some of the thermal parameters are estimated using values representative of the Inuvik area.

The curve denoted by $0^{\circ}C$ in Figure 4 represents the extent of the thawing predicted near the lagoon edge using a simple explicit finite difference technique to solve numerically the partial differential equation which describes time-independent heat conduction (Laplace's equation). It was assumed that all cross-sections of the lagoon are identical, which reasonably implies there is negligable heat flow parallel to the lagoon edge, and reduces the problem to consideration of two-dimensions.

To facilitate the convergence to a steady-state solution, three consecutively finer grids simulating the embankment cross-section were utilised, culminating in a square lattice of 42x49 points, the geometry of which is shown in the insert to Figure 4.

The mean annual soil temperature was assumed to be $-4\ ^{\circ}C$, a figure which was indicated from the preliminary readings from probe V and which is in general agreement with soil temperature data for the area (Brown, 1970).

The mean annual water bottom temperature in the lagoon was estimated to be $3.5\ ^{\circ}C$, which is compatible with values for shallow water bodies in the region (Smith, 1972).

The ratio of the conductivities of the underlying silt and the gravel embankment, whose depth was approximated by the dotted lines in Figure 4, was assumed to be 0.67.

The bottom and left-side boundaries of the finite difference lattice were fixed as isothermals of $-4.0^{\circ}C$ at a distance equivalent to 36 m and 15 m, respectively, from the water-line on the embankment face, and the right-side boundary was set as an adiabatic. This latter boundary acted as a plane of symmetry and gave the lagoon an effective width of about 30 m. This is considerably smaller than the actual lagoon width, but this departure from reality, and also the imposition of the subsurface isothermal boundaries, produces negligible effects in the immediate vicinity of the embankment.

Simple analytical solutions to the steady-state heat flow equation, which approximate some configurations occurring in permafrost problems, are available in the literature.

(Gold and Lachenbruch, 1973). One such solution, the flow of heat in a homogenous and semi-infinite solid with two adjacent, straight-sided, semi-infinite isothermal surfaces on the boundary, is included in Appendix 1. This simple configuration is a crude approximation to the lagoon edge.

The straight line denoted by A in Figure 4 represents the position of the thaw interface near the lagoon edge predicted by the analytical solution. The boundary temperatures used to obtain this line are the same as those utilized in the numerical calculation described above, namely, 4.0°C and 3.5°C. In this case, these two isotherms are assumed to lie along the horizontal line denoted as the X-axis in Figure 4, and their point of separation is taken as 0, which is the point on the X-axis vertically below the water-line at the embankment.

Also included in Figure 4 is another line, B, which indicates the predicted extent of the thaw utilizing the same boundary conditions and analytical solution, but with the not unreasonable assumption that the conductivities of the frozen and thawed soils are in the ratio of 2 to 1. The necessary mathematical details, verifying the generalization of the homogenous-medium, steady-state solution to a medium of temperature dependent conductivity, are included in Appendix 2.

The calculations described above are simple, preliminary attempts intended to give some indication of the approximate extent of the "average" thaw zone expected in the vicinity of the lagoon embankment.

6. RESULTS

6.1 Subsoil Conditions

The three holes drilled through the embankment indicated that the gravel layer was 2.5 m deep beneath the higher upstream section and approximately 1.25 m thick near the lower downstream toe. Below the gravel, a brown silt was present to the bottom of each test hole. It was apparent that the bottom portion of the gravel and approximately 0.6 m of the silt deposit was unfrozen. In fact, sloughing from this wet, unfrozen zone prevented sampling near the bottom of the two holes closest to the lagoon. The hole adjacent to the embankment indicated a 0.3 m topsoil cover above the silt strata.

One of the recovered samples contained a 15 cm thick lens, although most of the ice in the fine grain silt consisted of visible horizontal layers varying from 1 - 13 mm in thickness. Near the bottom of the test holes, the ground ice was classified as non-visible, well bonded with excess ice.

6.2 Sample Classification and Soil Parameters

The major physical and thermal parameters for the recovered soil samples are included in Table 2. Figures 5 and 6 also show curves summarizing the test hole logs for the four holes and a plot of the variation of water content with depth in the foundation soil.

The Inuvik silt deposit which comprises the majority of the geologic sequence was classified as a low plastic silt with a Unified Classification Symbol of ML. The Atterberg liquid limit for the silt varied from 20.4% to 33.9% with an average value of 25.6%. This average indicates that the clay content is generally low and that the samples consisted primarily of silts. Hydrometer analysis indicated that the silt strata contained an average of 5% clay sizes with a trace of sand and that the remainder consisted of silt.

Below the 30 m level the average liquid limit was 33.7% which indicates that the strata contains a greater clay content. A sample obtained from the 61 m level had a liquid limit of 42.4%, a clay content of 30% and was classified as an organic clay of medium plasticity.

The range of dry densities and ice contents obtained, varying from 0.64 g/cm^3 and 1.56 g/cm^3 and 42.0% to 78.6%, respectively, are typical for the Inuvik area. In general, the sampling indicated excess ice of approximately 70% near the original ground surface and that the ice content decreased with depth.

6.3 Thermal Regime

At this time, the temperature readings have been collected for a period of four months.

The initial readings, as expected, indicated some transient effects created by the perturbation associated with drilling. In particular, those holes in which sloughing of wet material occurred from the unfrozen zone showed anomalous temperature variations for about two weeks after the probes were installed. A simple calculation indicates that this is approximately the time taken for the wet material to freeze at a lower level.

The temperature readings confirm the observation made during the drilling, that a thawed zone exists within and immediately beneath the embankment. The approximate extent of this zone during the early winter (November, 1973) is indicated by the cross-hatched region in Figure 4. Further readings collected to the middle of February, 1974, indicate that this thawed zone is still present, though it is diminishing in size.

Readings from probe V indicate that the rather shallow active layer on the downstream side of the berm was apparently completely frozen by the beginning of January, 1974. Temperatures from this deep probe for the last two months of 1973 and the first two months of 1974 are included in Figure 8, and the readings between 45 m and 60 m indicate that the permafrost table is approximately 75 m thick in this vicinity.

The long-term effect on the thermal regime beneath the oxidation pond embankment created by the nearby East Channel of the Mackenzie River has been estimated and the modifications to the temperature profile for probe V are shown in Figure 8. The contribution is negligible above a depth of 15 m, but in absence of the river channel the permafrost table in the vicinity of probe V would probably be 10 m thicker.

Extrapolation of the temperature readings between the depths of 20 m and 45 m indicates that the mean soil surface temperature is approximately $-4^{\circ}C$.

7. DISCUSSION

Using the estimated surface and lagoon bottom mean temperatures used previously, and averaging the thermal parameters in Table 1, a one-dimensional thaw calculation (Nixon and McRoberts, 1973) indicates that the depth of thaw beneath the centre of the lagoon after almost two decades of operation will be approximately 6 m. The temperatures used in this calculation imply that after centuries of operation the thaw bulb beneath the lagoon would extend completely through the permafrost layer. Clearly, the steady-state condition has not been reached in this region beneath the lagoon. However, in the region of particular interest, within the embankment and its immediate foundation soils, the ground surface is relatively close and (periodic) steady-state conditions should essentially prevail. This implies that the thermal regime at the edge of the lagoon should now be independent of initial transient effects, such as a dependency on the particular time of the year when the embankment construction took place. Of course, other time-dependent effects are present because of random fluctuations and periodic annual and diurnal ambient temperature variations.

The simple mathematical modelling described in section 5.4 ignores the important contributions from the periodic temperature variations impressed on the boundary surfaces. However, these calculations have been included to indicate the "average" extent of the thaw zone in the vicinity of the embankment and they imply that the majority of the soil within and beneath the embankment should remain frozen.

In contrast, the temperature readings from the field show that an unfrozen zone exists in the gravel of the embankment core and extends into the underlying silts, at least, during the first half of the winter of 1973-74. It is likely that this thawed zone is caused by the periodic annual ambient temperature variations which create a particularly deep active layer through the gravel berm, by sensible heat transported via water seepage, or by a combination of both these mechanisms. Although evidence of excessive seepage through the embankment is not visibly apparent in the immediate vicinity of the field site, seepage icings of a considerable size were evident at the downstream toe of the embankment in an area about 150 m west of the sewer outfall during the early winter months of 1973 (Fig. 11).

8. CONCLUSION

Initial temperature data indicate that during the first half of the 1973-74 winter, at least, a thawed zone was present in the core and the immediate foundation soils of the lagoon embankment at Inuvik. Such a thawed zone is not predicted by preliminary steady-state calculations. These calculations indicate that a thawed zone should be limited to a small region near the upstream toe of the embankment.

Clearly, to make a quantitative simulation of the thermal regime within the embankment and foundation, it is necessary to consider time-dependent boundary conditions and also, possibly, the contribution to heat flow by seepage water.

The shallow thawed zone presently existing beneath the Inuvik lagoon embankment is apparently created by the exclusive use of gravel as a fill material in this case. Such a material exhibits a high permeability in the thawed state, creating the environmentally-damaging possibility of effluent leakage and also the occurrence of further thawing caused by heat transported by water movement. Further, the high thermal conductivity of such a coarse fill material encourages the undesirable development of a particularly deep active layer.

It seems likely that by an appropriate choice of fill materials, and possibly the suitable use of heat insulating layers, it may be possible to avoid the creation of similar undesirable, unfrozen zones in the future construction of wastewater impounding embankments in certain permafrost areas.

It remains necessary to continue temperature data collection from the present site for a full cycle - one year. The existing soil parameter data will be used in conjunction with the surface temperature data from the site for input into a model which will be used to simulate the time-dependent thermal regime in the vicinity of the berm. This model will then be used to interpret the processes at work in the present Inuvik lagoon embankment.

9. IMPLICATIONS AND RECOMMENDATIONS

These preliminary findings indicate that the exclusive use of coarse fill materials for the construction of waste water impounding embankments for workcamps or permanent communities in the North should not be encouraged because of the environmentally-damaging high seepage rates associated with such permeable materials. Further, coarse materials have relatively high thermal conductivities, thereby increasing the undesirable possibility of thawing the foundation soils; a feature which is probably compounded by the sensible heat supplied by seepage water.

It seems likely that the use of impermeable lining or grouting materials may prove necessary to ensure containment of waste water impounded by embankments of coarse fill materials.

Embankments constructed largely of fine-grained materials, which generally have relatively low permeabilities and conductivities, present an alternative approach. Seepage rates may be minimized using such materials and the possibility of maintaining a frozen foundation and embankment core are increased. However, in the North, such borrow materials are often obtained in the frozen state with a high ice content, and any thawing may result in low shear strengths and in slope stability problems. In such cases, it may be desirable to thaw and partially consolidate the material prior to placement. This will ensure that the water content of the embankment fill approaches reasonable engineering standards.

REFERENCES

Bogoslovskiy, P.A., Veselov, V.A., Ukhov, S.B., Stotsenko, A.V. and Tsvid, A.A. (1963). "Dams in Permafrost Regions". Proceedings of the First International Conference on Permafrost, pp. 450-455.

Brown, R.J.E. (1970). "Permafrost in Canada". University of Toronto Press.

Brown, W.G. and Johnston, G.H. (1970). "Dikes on Permafrost: Predicting Thaw and Settlement". Canadian Geotechnical Journal, Vol. 7, No. 4, pp. 365-371.

Carslaw, H.S. and Jaeger, J.C. (1959). "Conduction of Heat in Solids". Oxford University Press, Second Edition.

Fulwider, C.W. (1973). "Thermal Regime in an Arctic Earthfill Dam". Proceedings of the Second International Conference on Permafrost, North American Contribution, pp. 622-628.

Gold, L.W. and Lachenbruch, A.H. (1973). "Thermal Conditions in Permafrost - A Review of North American Literature". Proceedings of the Second International Conference on Permafrost, North American Contribution, pp. 3-25.

Johnston, G.H. (1969) "Dykes on Permafrost, Kelsey Generating Station, Manitoba". Canadian Geotechnical Journal, Vol. 6, No. 6, pp. 139-157.

Kersten, M.S. (1949). "Thermal Properties of Soils". University of Minnesota, Engineering Experiment Station Bulletin 28.

Mackay, J.R. (1963). "The Mackenzie Delta Area, N.W.T.". Geography Branch, Mines and Technical Survey, Ottawa, Memoir 8.

MacPherson, J.G., Watson, G.H. and Koropatnick, A. (1970). "Dikes on Permafrost Foundations in Northern Manitoba". Canadian Geotechnical Journal, Vol. 7, No. 4, pp. 356-364.

Nixon, J.F. and McRoberts, E.C. (1973). "A Study of Some Factors Affecting the Thawing of Frozen Soils". Canadian Geotechnical Journal, Vol. 10, No. 3, pp. 439-452.

Roy, M., LaRochelle, P. and Anctil, C. (1973). "Stability of Dykes: Embankments at Mining Sites in the Yellowknife Area". North of 60, IAND Publication No. QS-3037-000-EE-A1.

Smith, M.W. (1972). "Observed and Predicted Ground Temperatures, Mackenzie Delta, N.W.T.". Mackenzie Delta Area Monograph, 22nd. International Geographical Congress, pp. 95-106.

APPENDIX 1

The steady-state temperature within a semi-infinite solid with two isothermal regions separated by a straight line on the boundary surface

Figure 7 presents a section which is perpendicular to the line separating two isothermal surfaces at temperatures T_1 and T_2 imposed on the boundary of a semi-infinite solid of uniform conductivity. The boundary is denoted by the continuation of the line OX, with the point O representing the separation point of the two isothermal regions and which is taken as the origin of a set of cartesian coordinates as shown.

The set of steady-state isotherms on this diagram are represented by straight lines passing through the point O. The equation defining the temperature distribution is given by (Carslaw & Jaeger, 1959)

$$T(X,Y) = T_2 + (T_1 - T_2)\frac{\arctan}{\pi}(Y/X) \qquad (A1.1)$$

$$= T_2 + (T_1 - T_2)(\theta/\pi), \qquad (A1.2)$$

where θ is the angle between the line OX and the isotherm of temperature T.

If the region within which $T < T_f (T \leqslant T_f \leqslant T_2)$, say, has conductivity K_F and the remaining region where $T > T_f$ has conductivity K_T, then in the solution (A1.1) or (A1.2) replace T and T_2 by T' and T_2', respectively. Here,

$$T' = \begin{cases} (K_T/K_F)(T-T_f) + T_f; & T > T_f \\ T \qquad\qquad\qquad\quad ; & T < T_f \end{cases} \qquad (A1.3)$$

and

$$T_2' = (K_T/K_F)(T_2-T_f) + T_f \qquad (A1.4)$$

The verification of this transformation is included in Appendix 2.

APPENDIX 2

The solution to the steady-state heat flow between two isotherms in a medium when the conductivity is purely a function of the temperature

The diffusion equation which describes heat-conduction, in a three-dimensional medium of varying conductivity with no heat sources, may be written in cartesian co-ordinates as (Carslaw and Jaeger, 1959)

$$\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)=\rho c\frac{\partial T}{\partial t}\quad . \qquad (A2.1)$$

Here, ρ and c, respectively, represent the density and specific heat of the medium, K denotes thermal conductivity, and the partial derivative on the right-hand-side gives the variation of temperature with time. Specializing to the steady flow of heat in a region with time-independent boundary conditions, the partial derivative with respect to time makes no contribution and the equation becomes in more compact notation,

$$\text{div } K \text{ grad } T = 0 \quad . \qquad (A2.2)$$

Here, div and grad denote, respectively, the divergence and gradient operations of vector analysis.

When the thermal conductivity is purely a function of temperature (A2.2) may be rewritten as

$$\text{div.grad } T' = \nabla^2 T' = 0 \quad , \qquad (A2.3)$$

which is of the form for describing time-independent, steady-state heat flow in a medium of constant conductivity (Laplace's equation). In (A2.3), we have

$$T' = T_1 + \frac{1}{K_1}\int_{T_1}^{T} K\, dT, \qquad (A2.4)$$

where K_1 is the conductivity when $T = T_1$, the lowest boundary temperature. In appendix 1, the temperature variation assumed for K is

$$K = K_F + (K_T - K_F)H(T-T_f) \qquad (A2.5)$$

where, in this case, K_T and K_F represent the thermal conductivities of thawed and frozen soil, respectively, and T_f denotes the freezing temperature. In (A2.5), $H(T-T_f)$ is the Heaviside step-function, given by:

$$H(T-T_f) = \begin{cases} 0 & T < T_f \\ \\ 1 & T > T_f \end{cases} \qquad \text{(A2.6)}$$

Solving (A2.3) with the boundary conditions prescribed in Appendix 1 recovers (A2.1) or (A2.2) and substituting (A2.5) into (A2.4) generates the transformation given by (A1.3) and (A1.4).

APPENDIX 3

TABLES & FIGURES

Table 1: PHYSICAL AND THERMAL SOIL PARAMETERS

Test Hole Probe No.	Hole Depth (m)	Effective Depth (m)	ρ_w (g/cm^3)	ρ_d (g/cm^3)	w (%)	V_I/V (%)	K_T (mcal/ s cm °C)	C_F (cal/ cm^3 °C)	C_T (cal/ cm^3 °C)	L (cal/cm^3)
IV	1.5	0.3	1.39	0.64	115.5	75.9	0.15	0.50	0.87	53.6
III	2.7	0.6	1.68	1.16	44.5	56.8	0.25	0.49	0.75	37.2
III	3.0	0.9	1.94	0.76	153.5	71.4	0.15	0.74	1.33	84.4
V	1.2	1.2	1.36	0.57	139.4	78.6	0.15	0.51	0.91	57.2
IV	3.6	2.4	1.76	1.20	47.2	55.1	0.25	0.52	0.81	40.8
II	5.2	2.7	1.76	1.27	38.3	52.4	0.29	0.50	0.74	35.1
V	2.7	2.7	1.82	1.28	43.1	52.2	0.27	0.53	0.80	39.6
V	4.9	4.9	1.79	1.22	45.9	54.1	0.25	0.53	0.81	40.4
II	7.9	5.5	2.00	1.49	34.3	44.3	0.31	0.55	0.81	36.8
IV	9.1	7.9	1.97	1.53	28.5	42.6	0.34	0.52	0.74	31.4
IV	10.7	9.4	1.98	1.56	26.6	42.0	0.36	0.52	0.73	29.9

LEGEND FOR TABLE 1

The effective depth shown in Column 3 represents the depth below the top of the foundation soil.

ρ_w = wet density

ρ_d = dry density

w = water content as a percent of dry unit weight

V_I/V = volumetric ice content as a percent of total volume

K_F = conductivity of frozen soil

K_T = conductivity of thawed soil

C_F = volumetric heat capacity of frozen soil

C_T = volumetric heat capacity of thawed soil

L = volumetric latent heat of soil

The conductivities given in table 2 are evaluated using the data of Kersten (1949). The frozen soil conductivity for all the samples collected is 0.52 mcal/s cm ^{o}C (Nixon and McRoberts, 1973).

The volumetric heat capacities and latent heats were evaluated using the relations given by Nixon and McRoberts (1973) and, for the latter parameters, assuming that 10% by mass of the total water content was unfrozen.

LEGENDS FOR FIGURES

Figure 1 Plan of the sewage lagoon at Inuvik, N.W.T., indicating the location of the field study.

Figure 2 Plan of the study site at the lagoon embankment at Inuvik, N.W.T., indicating the positions of the thermal probes.

Figure 3 Cross-section of the embankment at the study site indicating the positions of the temperature stations.

Figure 4 Cross-section of the embankment at the field site indicating various thaw boundaries. The cross-hatched region indicates the approximate extent of the thawed zone within the gravel embankment, whose extent is represented by the dotted lines, and foundation soils during the early winter (November) of 1973. The curve denoted by $0^{o}C$ represents the extent of the thawing predicted by an explicit finite-difference numerical solution to the steady-state heat flow problem. The line A indicates the position of the thaw interface predicted using the analytical solution for the steady-state heat flow in a homogenous, semi-infinite solid beneath a straight boundary between two isothermal surfaces. The line B is derived in the same manner as line A, but assuming the ratio of the frozen to thawed soil conductivities is 2. The insert indicates the finite difference grid utilized in the numerical simulation.

Figure 5 Soil Gradation Curves. The cross-hatched area denoted by A represents the range of gradation curves for seven samples collected from the four bore holes at various depths between 8 and 26 feet. Curve B is the gradation curve for an air-returned sample recovered from hole V from a depth of 200 feet.

Figure 6 The variations of water content with depth in the four bore holes. The effective depth represents the depth in the foundation soil i.e. the actual depth minus the embankment thickness.

Figure 7 Schematic representation of the lagoon edge used for the steady-state, analytical heat flow calculation in Appendix 1.

Figure 8 Temperature readings from probe V. The mean monthly temperature variation with depth for November, December, 1973 and January, February, 1974. The geothermal gradient between 20 m and 45 m indicates a mean annual surface temperature of

approximately $-4^{o}C$. The contribution to the temperature profile from the East Channel of the Mackenzie River is indicated.

Figure 9 The Nodwell mounted Mayhew rig drilling through the Inuvik embankment. Probe I was lowered through the cut in the ice in the foreground.

Figure 10 The Inuvik lagoon embankment, looking NW, showing the completed termination boxes on both sides of the embankment.

Figure 11 An extensive seepage icing at the end of October 1973, near the downstream toe of the Inuvik lagoon embankment in an area about 500 ft. NW of the sewer outfall.

FIGURE 1 PLAN OF INUVIK LAGOON

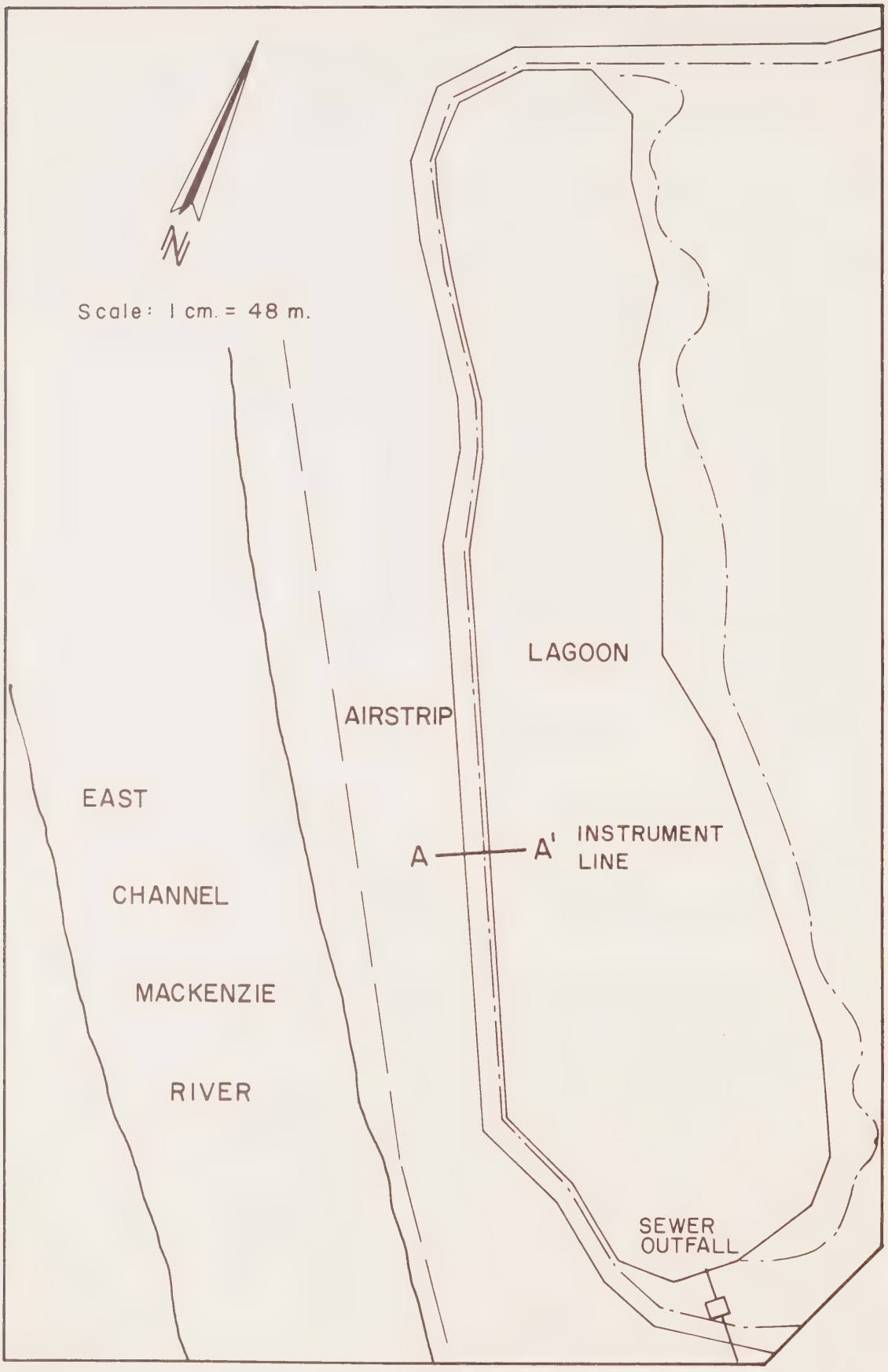
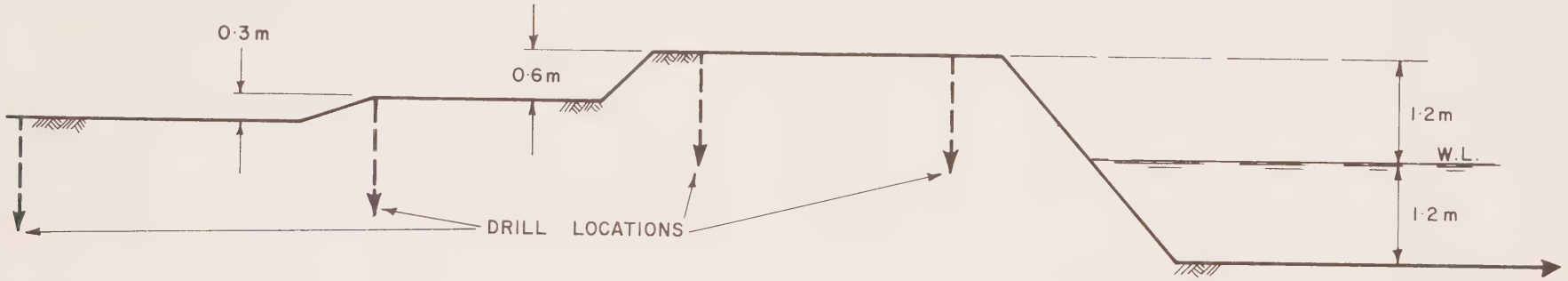
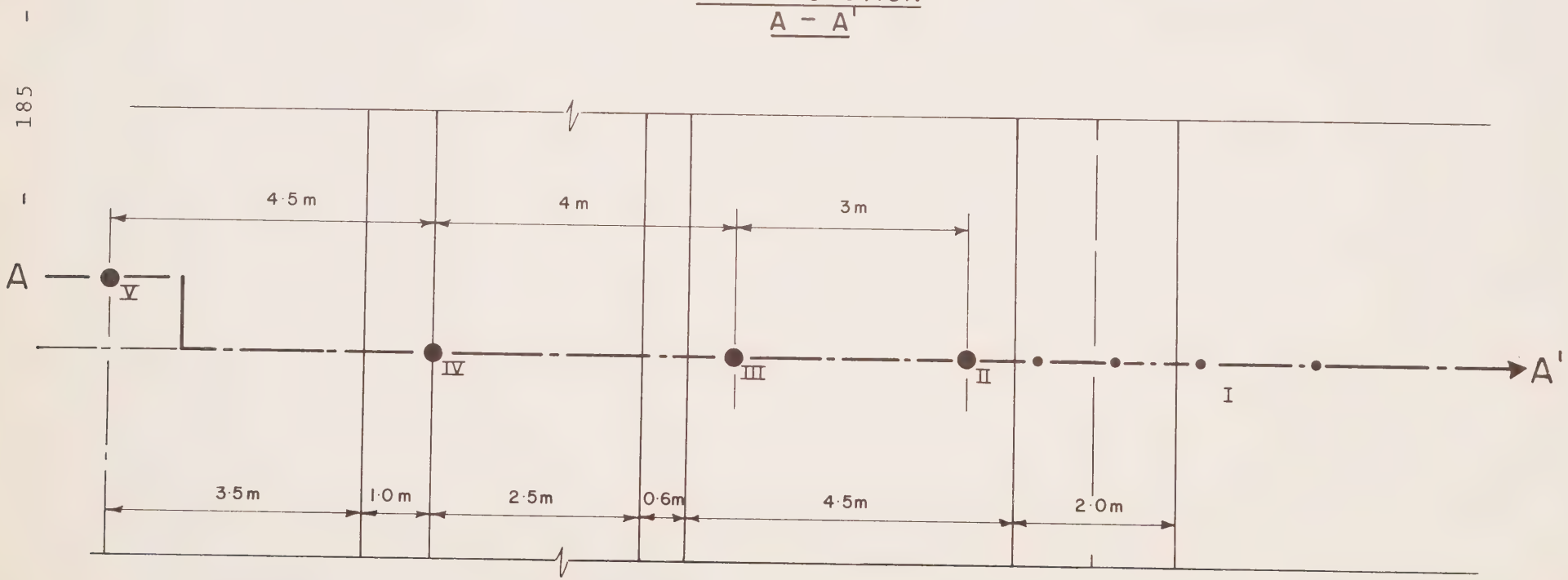


FIGURE 2 PLAN OF STUDY SITE



CROSS SECTION
A - A'



PLAN VIEW

Scale

FIGURE 3. LOCATIONS OF THE TEMPERATURE STATIONS

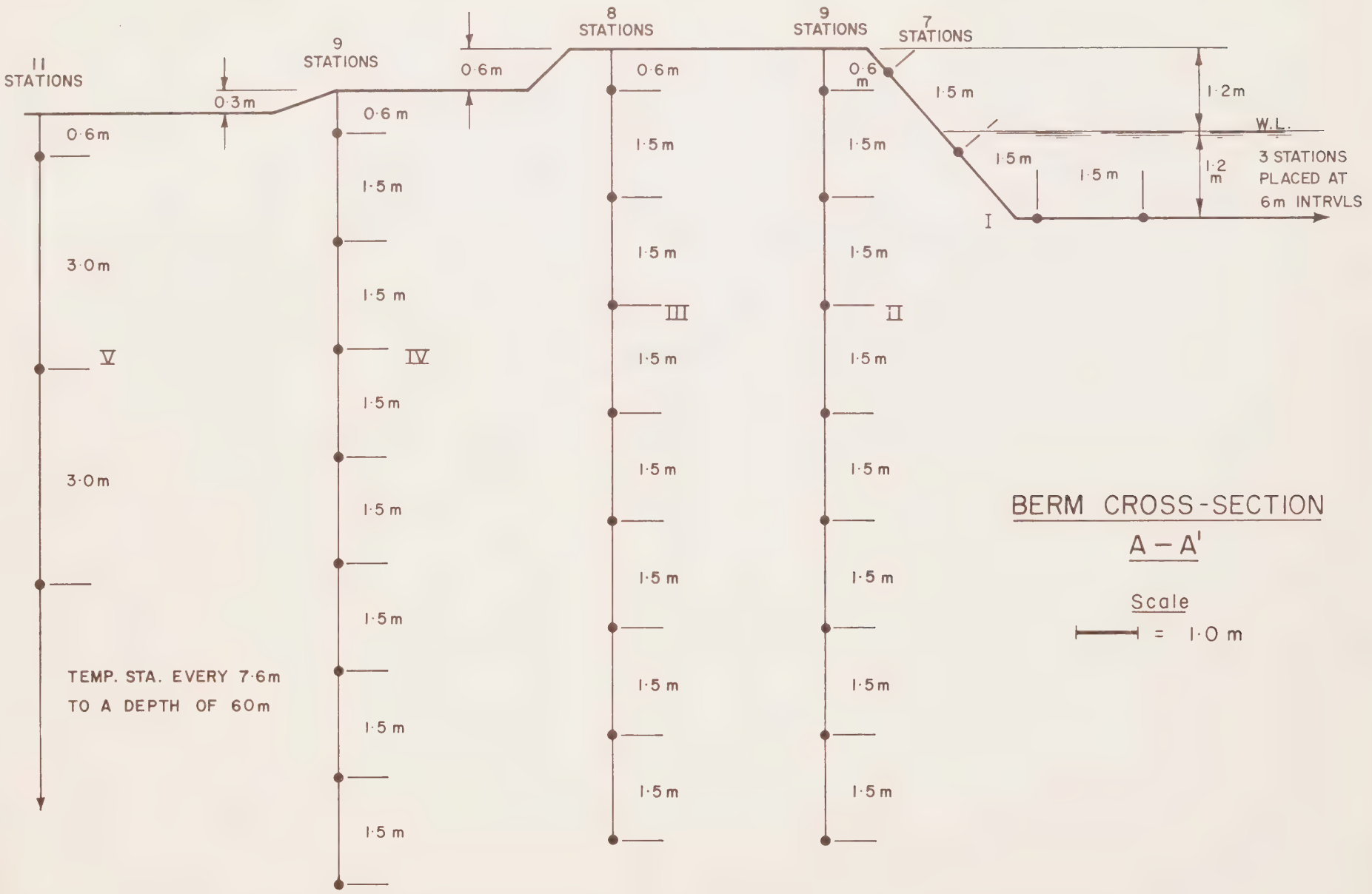


FIGURE 4 THAW BOUNDARIES IN THE INUVIK LAGOON EMBANKMENT

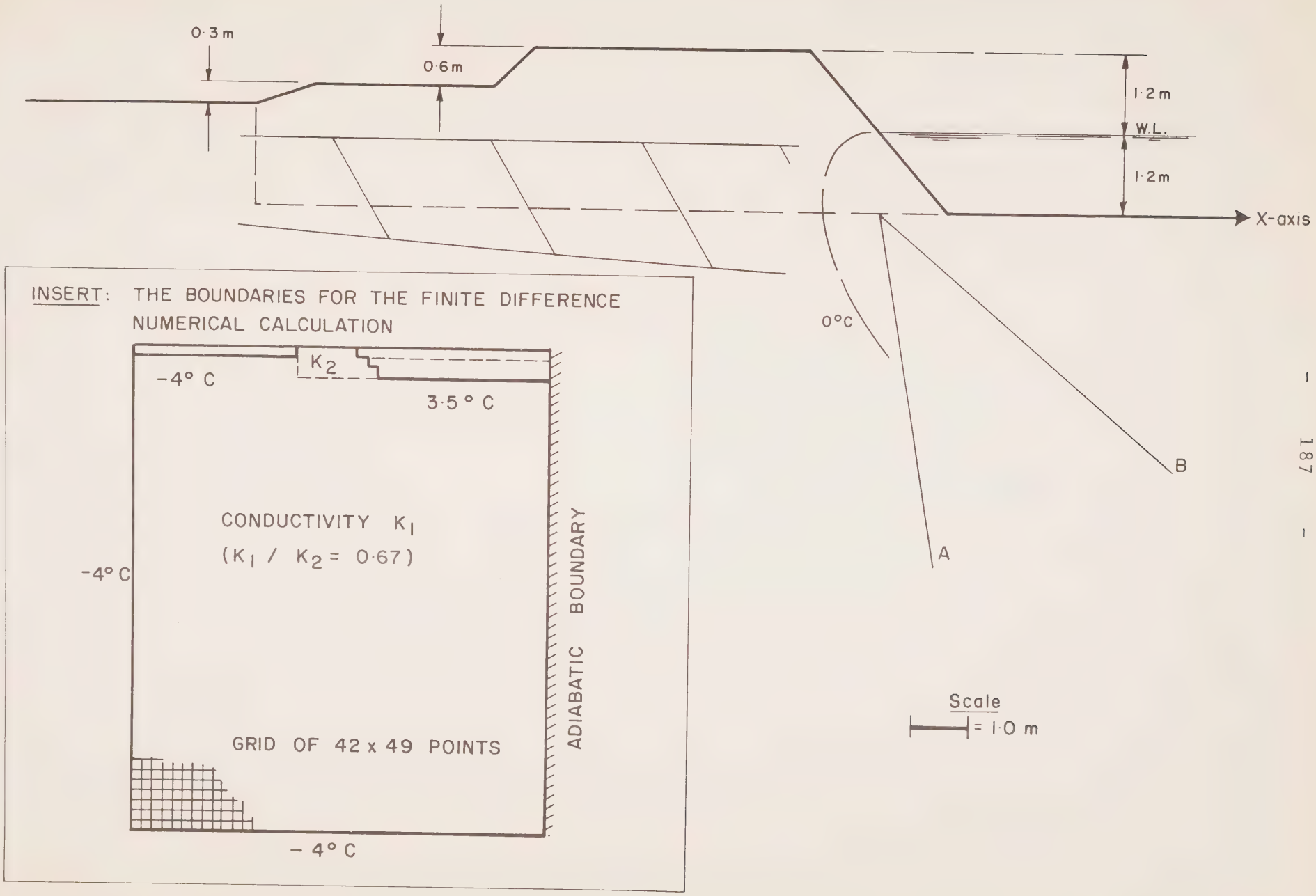


FIGURE 5 GRADATION CURVES

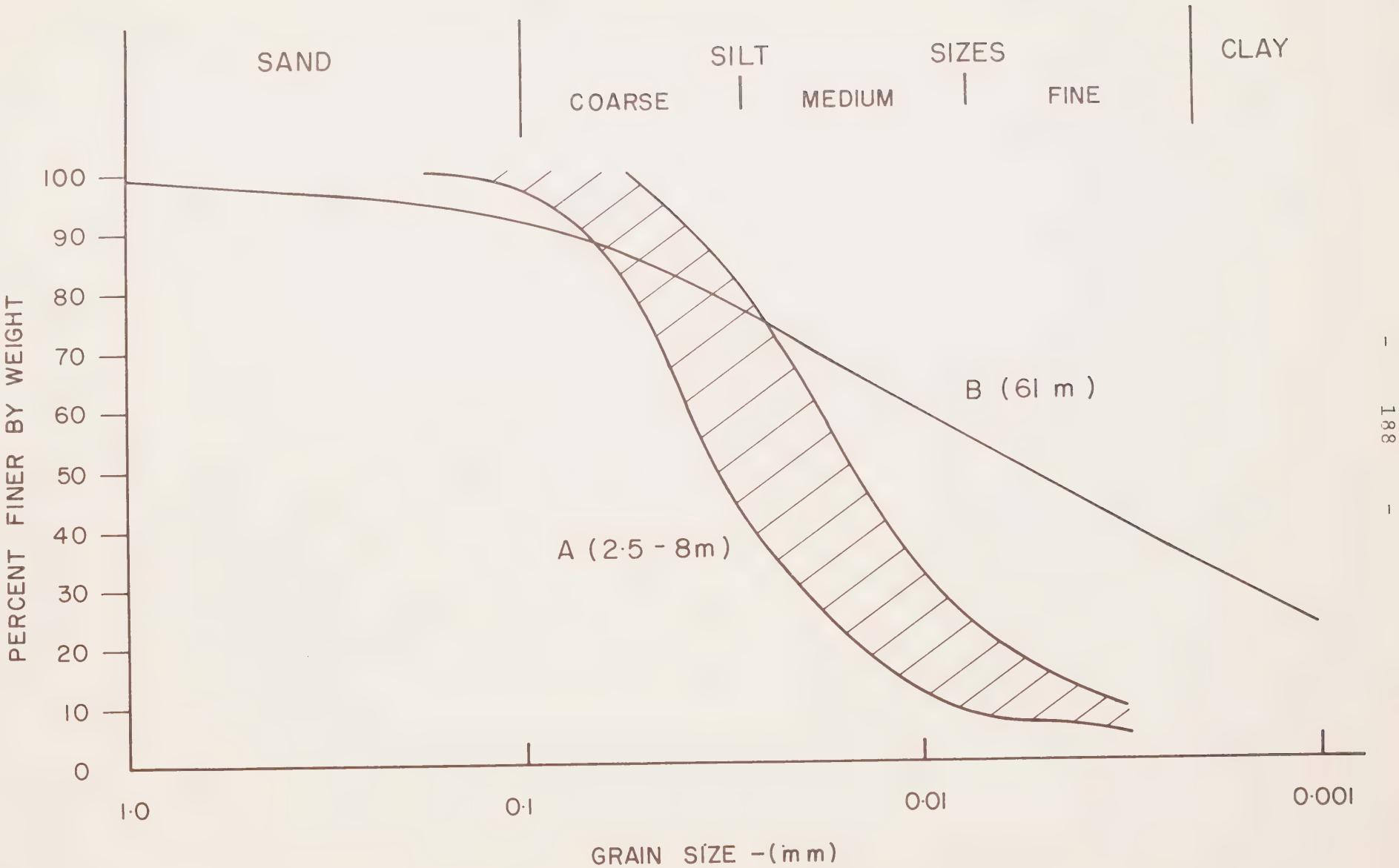


FIGURE 6 WATER CONTENT Vs. EFFECTIVE DEPTH

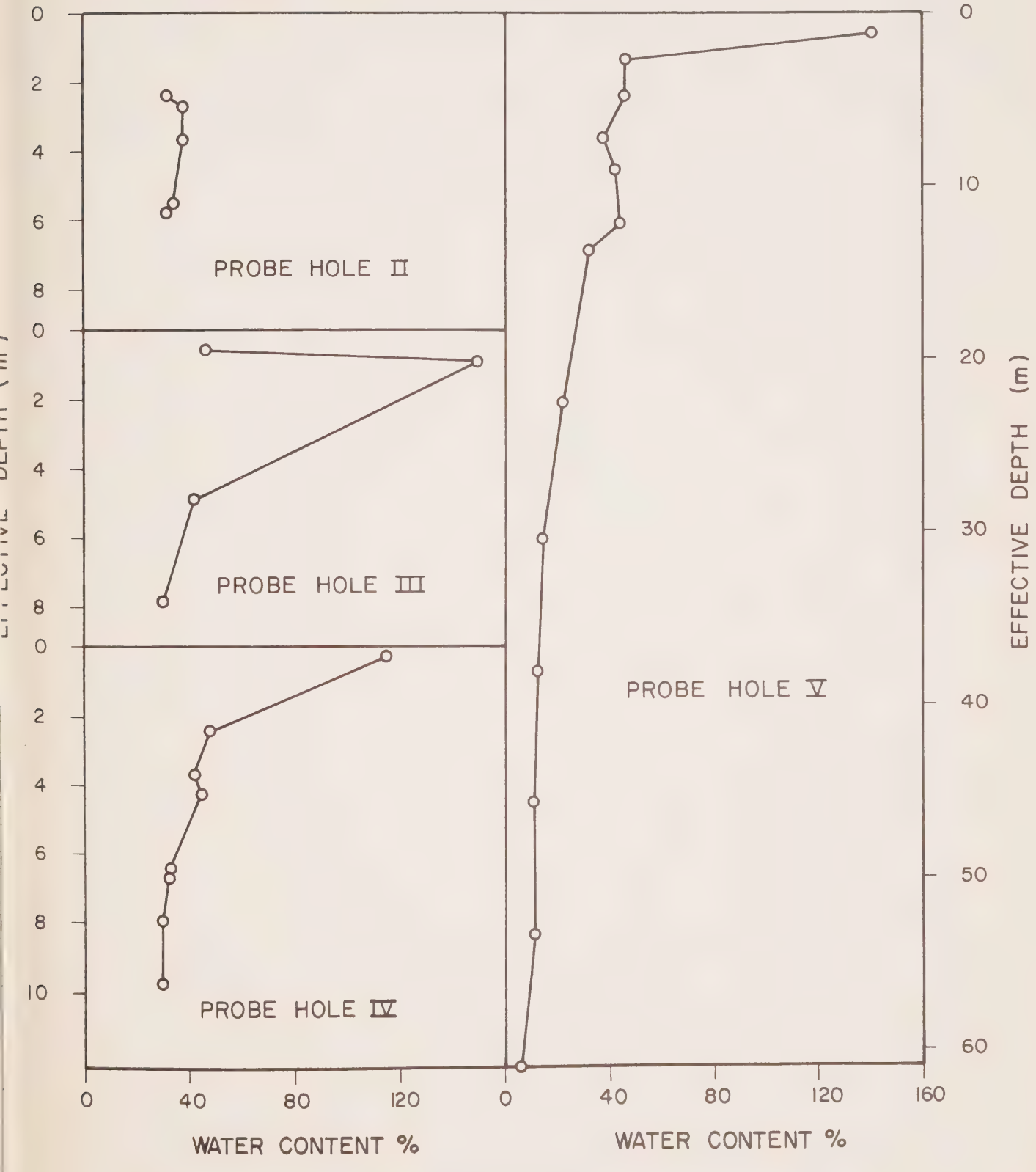


FIGURE 7 SCHEMATIC REPRESENTATION OF THE LAGOON EDGE

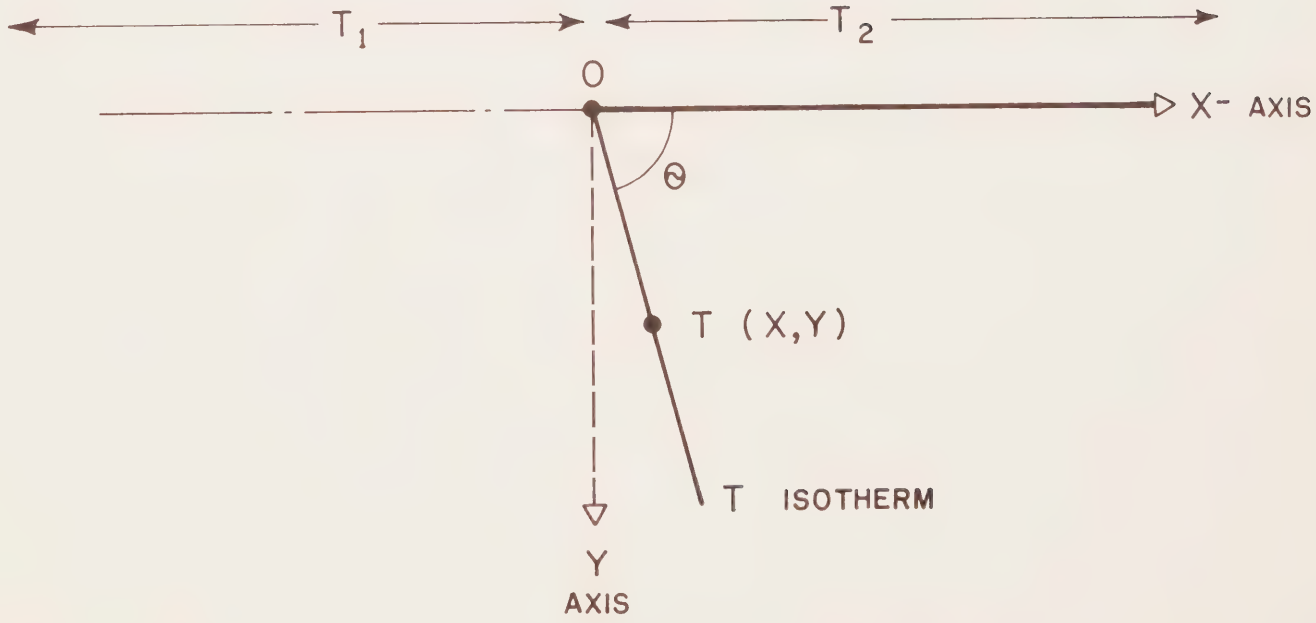


FIGURE 8 TEMPERATURE READINGS FROM PROBE V

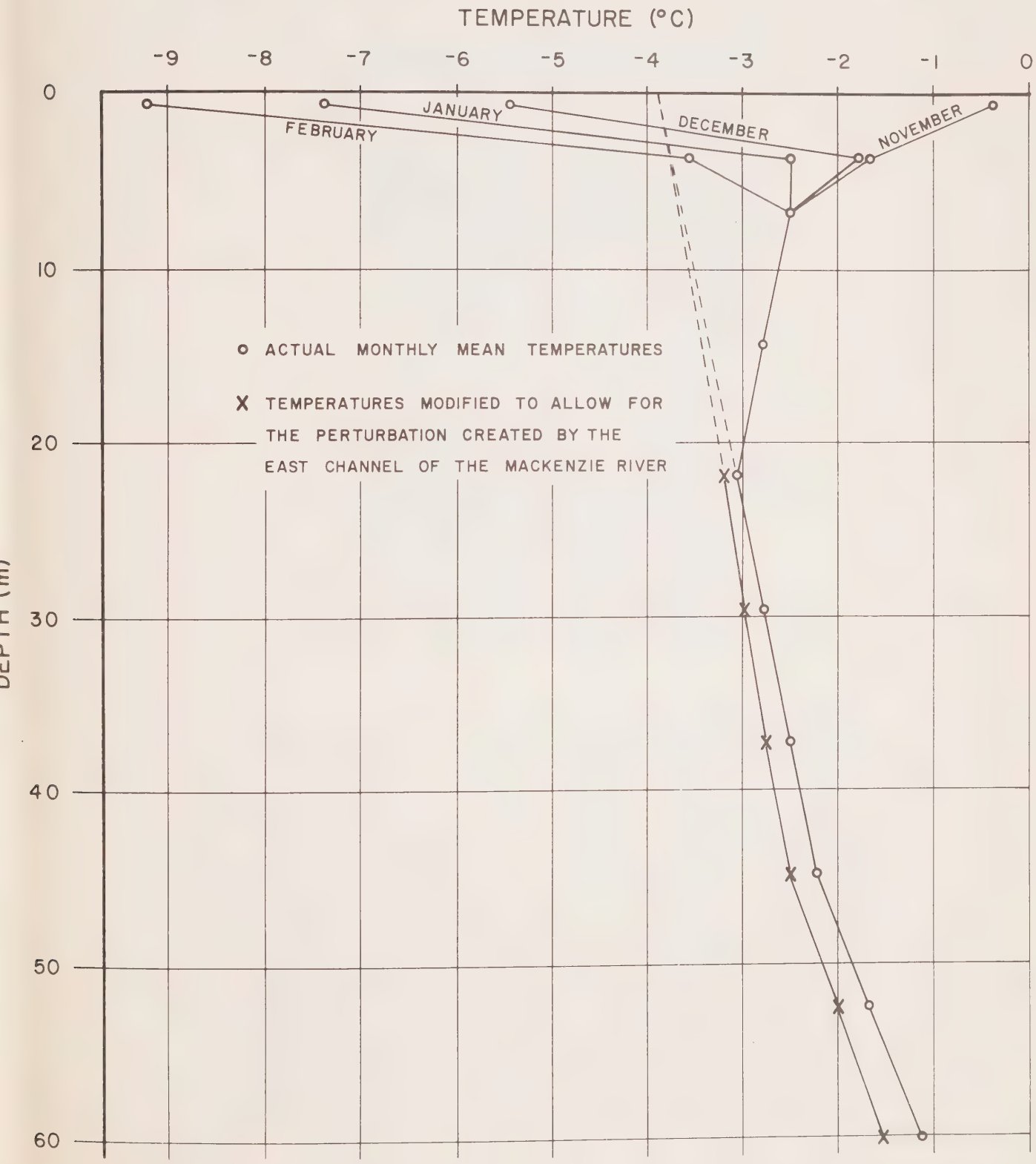


Fig. 9 The Nodwell mounted Mayhew rig drilling through the Inuvik embankment. Probe I was lowered through the cut in the ice in the foreground.

Fig.10 The termination box on the upstream side of the embankment.

Fig. 11 An extensive seepage icing at the end of October 1973, near the downstream toe of the Inuvik lagoon embankment in an area about 150 m NW of the sewer outfall.

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TERMS OF REFERENCE

A contract was signed on October 15, 1973, between the Environmental Protection Service and the University of Toronto to carry out the following work:

1. To prepare a preliminary report on alternatives for disposal of concentrated human wastes collected in 'honeybags', from future collection systems, such as vacuum sewers or pressure sewers, and sludge from treatment plants. Proposals for detailed work on possible solutions are to be included. The solids handling problem as well as final disposal problem is to be investigated.

2. To carry out a laboratory investigation on disposal of human waste in permafrost. Several physical-chemical and microbiological parameters will be monitored on the decomposition taking place in laboratory reactors designed to simulate a sludge pit - anaerobic digestor under low temperature conditions. Waste will be selected to simulate contents of 'honey-bags'.

Reports were to be submitted by April 15, 1974. It was the clear understanding of both parties involved that this investigation will extend over several years, and that only preliminary results can be expected after a few months of work. I was assisted in the study by Mr. Durga Prasad, M.Sc., Technologist, and Mr. Mohammed Elamin, B.A.Sc., Graduate Student, whose conscientious work is acknowledged.

The report is arranged to briefly state the nature of the problem and to summarize the findings to date. Where possible at this time recommendations are made. Item 1 is reported on in Part I Collection and Disposal Systems for Concentrated Wastes and item 2 in Part II Laboratory Investigation of Decomposition of Human Wastes in Permafrost.

STATEMENT OF THE PROBLEM

Many communities in the Northwest Territories and the Yukon Territories rely on trucked supply of water and pick-up of human waste. The high capital cost of conventional water and gravity sewer systems and limited funds necessitate the continued use of trucked systems for many years, particularly in the smaller settlements in permafrost regions. Bucket toilets, with or without the use of chemicals, are widely used. Their contents, in plastic bags ('honey-bags'), are picked up several times a week and trucked to dumps, sludge pits, or dumped into lagoons, the previous practice of disposal to the sea or on ice being no longer permitted. Water flush toilets are also in wide use. They include the conventional 3-5 gallon flush toilet and also low water usage toilets, of which the 'Flush-O-Matic' unit, using one quart of water per flush, is an example. These require connection to a storage tank in the home which is generally pumped out once a week. Normally, other household liquid wastes from kitchen sinks, bathtubs and laundry are not connected to the holding tank. Therefore, sewage from holding tanks is more dilute than contents of 'honey-bags', but still generally more concentrated than sewage in a gravity sewer system. There are several installations of self-contained toilets, such as incinerating toilets and chemical recirculating toilets, but they are not in widespread use.

The elimination of the use of 'honey-bags' would be a very important improvement in the living conditions of northern communities by contributing to a reduction in waste-borne diseases. Proper treatment and disposal methods for contents of 'honey-bags' are therefore probably only required for the next ten to twenty years. However, promising methods of piped collection of concentrated wastes are now being tested for use in northern communities. They include vacuum sewer and pressure sewer systems. Both require only small quantities of water for transport of solids. In addition, trucking of sewage from holding tanks will continue to be used. There is, therefore, a long-term need for treatment and disposal processes for wastes which are much more concentrated than domestic sewage transported by gravity. Since much of the process and cost of conventional sewage treatment lies in concentrating solids from dilute sewage, the advantage of receiving relatively undiluted waste for treatment is obvious. In addition, treatment and disposal of sludges from conventional sewage treatment plants, which will be built in communities served by gravity sewers, will require methods applicable for northern conditions. Finally, joint treatment of refuse, human waste and sludge is a possibility. The task, therefore, is to search out and test promising methods of collection and treatment for concentrated wastes to ensure their safe disposal to the environment.

SUMMARY AND RECOMMENDATIONS

It must be emphasized that the scope and resources for this report were very limited and that the recommendations are only preliminary. They are expected to be revised and enlarged upon in subsequent work. Because of the closeness of topics of Part I and II, necessitating some overlap, the summary and recommendations are presented together at the beginning of the report.

1. Concentrated Human Wastes include ' honey-bag' wastes, holding tank wastes, black water from vacuum sewers and pressure sewer wastes, and sludges from sewage treatment plants. There is limited information available in the North American literature on quantities and strength of these wastes. A preliminary search of Japanese literature on night soil and Swedish literature on black water and grey water from vacuum sewers has provided limited data on quantity and strength of these wastes. Studies on human waste quantities and strengths carried out under this contract agree reasonably well with the literature values.

   Recommendation 1: It is recommended that a thorough search of Japanese, Indian and other Asian literature be carried out regarding concentrated human wastes and their disposal. Work should be carried out to provide Canadian comparison. On pilot projects for vacuum and pressure sewers monitoring of quantity and strength of waste should be done.

2. Collection Systems

   The presently-used collection systems for concentrated wastes are mainly the trucked 'honey-bag' system and a trucked system for holding tank wastes. The elimination of the 'honey-bag' system in most communities would be a large step forward in improving living conditions in northern communities. Trucking of large quantities of holding tank wastes is expensive. Both systems will, however, continue to be used for many years in the smaller settlements, due to a lack of capital funds and local conditions. The vacuum sewer and pressure sewer systems are attractive alternatives to collect concentrated wastes. They avoid the need of excessive dilution of wastes required for transport in gravity sewers. Very recently, pilot tests on vacuum sewer and pressure sewer systems, adapted to northern conditions, have been started. There are many advantages in using the new systems. Their ability

to operate satisfactorily in northern communities has to be proven, but I am confident of their success, where local conditions make their use sensible.

Recommendation 2: It is recommended that pilot plant work under way on vacuum sewers and pressure sewers be increased substantially to obtain proof of their ability to function under northern climates and operating conditions. Close contact with similar work under way in Alaska is recommended to avoid unnecessary duplication of efforts.

3. Treatment and Disposal Systems

Present methods of disposal of 'honey-bag' wastes include the open dump, together or separate from garbage and refuse, sludge pits and lagoons. They leave much to be desired from many points of view. Adequate treatment methods for these concentrated human wastes are required for those communities that will continue to use the 'honey-bag' system for many years. The use of vacuum sewers and pressure sewers brings about the need for adequate treatment methods for these wastes, which will be more dilute than 'honey-bag' wastes, but much more concentrated than normal domestic sewage. Treatment and disposal processes include long-term storage, anaerobic digestion, lime precipitation, incineration and aerobic digestion.

Recommendation 3: It is recommended that a pilot project on 'honey-bag' disposal station similar to the Greenland type be started immediately in at least one northern community. It is further recommended that research efforts on adequate treatment methods for concentrated wastes from 'honey-bag' and vacuum and pressure sewer systems be increased substantially. Funds should be set aside as soon as possible to permit construction of several pilot projects as soon as laboratory research has advanced sufficiently.

4. Disposal of Human Wastes in Permafrost

One common method of disposal of 'honey-bag' wastes is to store them in pits, excavated in permafrost, which are covered with soil when full. Little or no information is available on any long-term decomposition of wastes and on the acceptability of this method for health and ecological safety. A simulated sludge

pit has been set up in the laboratory (see Part II). It is operated at -5°C. Measurements of physical, chemical and bacteriological parameters have been made weekly for the past three months. Data to date are too sparse and taken over far too short a time to draw any conclusions. They indicate so far that no measurable decomposition takes place in the pit, and that bacterial counts are drastically reduced from feed values due to freezing. Data on survival rates of pathogenic organisms are inconclusive so far.

Recommendation 4: It is recommended that the sludge pit be continued to operate for at least one year, if not longer, and that measurements now taken be continued. The frequency of sampling can be decreased to once per month. Temperature should be raised to about +5°C. for about three months to simulate summer conditions.

5. Anaerobic Digestion

Anaerobic digestion, a process widely occurring in nature, is a biological process in which complex organic matter is converted to methane and carbon dioxide in the absence of oxygen, thus decomposing organic waste. It will come about naturally in the storage of concentrated human waste. Heat is produced in the process. It can be made to work much more efficiently in an engineered reactor, where environmental conditions such as temperature, pH, mixing, etc., are controlled. The liquid effluent from such a reactor will require further treatment, most likely of a physical-chemical form, before discharge to the environment. Some further treatment and ultimate disposal of sludge is also a necessity.

Recommendation 5: It is recommended that current laboratory studies (see Part II) on anaerobic digestion under low temperature conditions be continued with the objective of establishing design criteria and operating conditions for future installations. Pilot plant studies in a northern community will be required once laboratory studies are completed. This should be carried out for concentrated wastes, such as 'honey-bag' wastes, as well as for more dilute wastes from vacuum and pressure sewer systems. Work on possible treatment methods for the supernatant and sludges are to be included. The possible effect of the use of chemical inhibitors in the 'honey-bag' system on anaerobic digestion should be studied.

I-1 CONCENTRATED HUMAN WASTES

1.1 DEFINITION:

For the purpose of this report the term 'concentrated wastes' shall include the following:

- Human waste, faeces and urine, from bucket toilets normally collected in plastic bags, called 'honey bags'. These wastes will be referred to from now on as *'honey bag' wastes.*

- Human waste, faeces and urine, from low water usage toilets connected to holding tanks in the house. These wastes will be referred to from now on as *holding tank wastes.*

- Human waste, faeces and urine, from vacuum toilets normally connected to a vacuum holding tank at the house or to a vacuum sewer system. These wastes will be referred to from now on as *black water.*

- Human waste, faeces and urine, from toilets used in conjunction with a pressure sewer system. These wastes will be referred to from now on as *pressure sewer wastes.*

- Sludge from sewage treatment plants.

In addition to these toilet wastes, household liquid wastes are generated from kitchen, bathroom tub and sink, laundry, etc. They are not included in concentrated wastes, but will require discussion in the report. They are referred to as *liquid wastes* or as *grey water wastes* (for vacuum sewers only). Garbage, refuse and other solid wastes are referred to as *solid wastes.*

1.2 QUANTITIES AND CHARACTERISTICS OF HUMAN WASTES:

Human body wastes (faeces and urine) are excreted in quantities varying with age, sex, and the diet. Fecal matter contains food residues, the remains of bile and intestinal secretions, cellular substances from the alimentary tract, and microbial flora (Fair *et al*, 1968). Various authorities claim that, on an ordinary mixed diet, the daily fecal excretion by an adult male will aggregate 110-170 g. with a solid content ranging between 25 and 45 g.; the fecal discharge of such an individual upon a vegetable diet will be much greater and may even be as great as 350 g. and possess a solid content of 75 g. (Hawk *et al*, 1937).

The volume of urine excreted by normal individuals during any definite period fluctuates within very wide limits. The average normal excretions of urine fall within the range of 1000 to 2000 ml. The volume excreted is influenced greatly by the diet, particularly by the ingestion of fluids, and by the ambient temperature which affects not only fluid intake but also loss of water through perspiration (Hawk *et al*, 1937; Spector, 1956).

The moisture content of fresh excrement changes with the type of diet and environmental temperature. Evaporation of water may occur under certain conditions. Little information is available on the characteristics of human body waste in the North American Sanitary Engineering literature. However, medical literature contains considerable information, but unfortunately the information is reported in different units suited to medical fields and comparable parameters are not collected in all studies. Physical and chemical characteristics of human body waste taken mainly from medical literature, calculated and converted to units used in sanitary engineering field are listed in Table I.

Some information is available on the characteristics of human body waste (night soil) from Japan, where night soil collection is the most common domestic waste disposal system. In Japan, night soil accumulates at a rate of 1.0 - 1.1 litres per day per person, compared to values of about 1.3 - 1.5 litres per day per person in Canada and U.S.A. It is a mixture of faeces and urine which, during storage in the privy vault, has undergone putrefaction to some extent (Ikeda, 1972, and Iwai *et al*, 1962). Table II shows some characteristics of Japanese night soil. Comparing the strength of the human waste reported and indicated in Table I and II, the strength of the waste reported from Japan, appears to be less than half of that of North American waste. This can perhaps be attributed to the diets, body size and other factors mentioned earlier. Further literature search in Asian journals during the next year may provide additional information.

1.3 HOLDING TANK WASTES AND BLACK WATER WASTES:

Low water usage type toilets and vacuum toilets require about 1 quart (or litre) of water for rinsing purposes. With the assumption of an average of 7-8 flushings per person per day the total volume of holding tank wastes or black water wastes generated can be estimated as 1.3 litres of faeces and urine and 7.5 litres of rinsing water, or approximately 9 litres

TABLE I

VOLUME AND CHARACTERISTICS OF HUMAN BODY WASTE

(Values are expressed in units shown/adult/day except for pH)

	Volume in Litres	Total Solids gm.	BOD gm.	Total Nitrogen Load gm.	Total Phosphorus Load gm.	pH
Urine	1.16	56.0	--	12.2	1.1	(4 to 8) 6.0
Faeces	0.14	26.0	--	1.5	0.4	(7.0 to 7.5)
Total	1.3	82.0	64.0	13.7	1.5	
Reference	Spector, 1937	Spector, 1937	Spector, 1937	Painter & Viney, 1959	Fair *et al*, 1968, and Hawk, 1937	Hawk *et al*, 1937

TABLE II

CHARACTERISTICS OF HUMAN BODY WASTE (NIGHT SOIL) FROM JAPAN

Reference	pH	Total-N mg/l	NH4-N mg/l	Total Solids gm/l	Suspended Solids gm/l	Volatile Solids gm/l	COD gm/l	BOD gm/l	Calorific Value Kcal/l.
Ikeda 1972	8.5	--	3,471	30.1	12.0	17.6	--	10.19	--
Iwai *et al*, 1962	8.5	--	--	31.5	--	20.4	37.8	12.8	107.5

(or 2 gal.) per person per day, with a maximum of about 50% more.* This assumes that household liquid wastes are not connected to the holding tank or a vacuum sewer system. They could account for 20-120 litres (5 to 30 gal.) per person per day, depending on the sophistication of the water supply system.

As a comparison Olsson, Karlgren and Tullander (1968) have estimated volumes of black water of 8.5 litres/person/day and grey water of 120 litres/person/day for Swedish practice.

Waste production with conventional 3-5 gal. water closets and all liquid wastes discharged to the gravity sewer system average about 40-60 gal./person/day, of which about half is contributed by toilet flushing. A comparison indicates that the use of low water usage toilets or vacuum toilets results in a volume of highly polluted wastes of about 5% of wastes produced in a conventional system, and in relatively unpolluted liquid wastes of about 50% volume compared to that of a conventional system.

Olsson, Karlgren and Tullander (1968) provide extensive information on physical-chemical and bacteriological parameters on black water and grey water in Sweden. A few selected parameters are given in Table III. As a comparison data are presented from work done in this contract on concentrated wastes (from Table V) and to literature averages on concentrated wastes (from Table I).

---

* Cadario and Heinke (1972) reported water consumptions varying from 1 to 5 gallons (4 to 20 litres) per person per day for communities in the Northwest Territories on holding tank systems with the lower figures predominating.

TABLE III

CHARACTERISTICS OF BLACK WATER AND GREY WATER

Parameter	Units	BLACK WATER			GREY WATER	
		Olsson *et al*	Calc.* from this Report (Table V)	Calc. from* Literature (Table I)	Olsson *et al*	This Report
Volume	l/person/day	8.5	8.8	7.8	120	--
	gal/ " / "	1.9	2	1.7	27	--
BOD_5	mg/l	2317	-	-	203	--
COD	mg/l	8500	20,000	11,900	408	--
Solids-Total	mg/l	6250	13,600	9,300	666	--
Phosphorus	mg/l P	190	190	170	19	--
Nitrogen	mg/l N	1280	1,360	1,590	9	--

* On assumption of a dilution of 1.3 litres of faeces and urine by 7.5 litres of water.

Agreement of most parameters is quite reasonable. Higher solids and COD values of results of this report compared to literature are noted.

Pressure sewer wastes are expected to produce volumes and strength of about the same quantities as for vacuum sewer systems. No accurate information on solid waste quantities in northern communities is available. Qualitative statements are given in several reports that, in native homes, very small quantities of garbage and refuse are accumulated, with very few combustible materials, that in white homes quantities are larger and contain more combustible material, particularly in construction camps and military installations, where quantities may be higher per person than in southern communities. All report higher accumulations of scrap, machine parts, abandoned equipment and the ever-present oil drum than in comparable southern communities. There is a need for quantitative information on amounts and character of garbage and refuse in northern communities and camps.

I-2 COLLECTION SYSTEMS

2.1 GENERAL:

Hanks (1967) has conducted an exhaustive literature study on the relationship of solid wastes (including human wastes) and disease. While the literature failed to permit a quantitative estimate of any solid waste/disease relationship, he had this to say in summary:

> "The communicable diseases most incriminated are those whose agents are found in fecal wastes - particularly human fecal wastes. Where these wastes are not disposed of in a sanitary manner, the morbidity and mortality rates from fecal-borne diseases in the population are high. Despite the fact that other factors are known to contribute to some reduction of these rates, the inescapable conclusion is that the continued presence in the environment of the wastes themselves is the basic causative factor. Therefore transmission -- whether by direct contact vector transfer, or indirect contact -- is due to environmental contamination by these wastes."

I cannot think of any place in North America where this statement applies more than in most of our northern communities. There is a lack of conclusive data of solid waste/disease relationship in our northern communities, but the problem is there.

2.2 TRUCKED 'HONEY-BAG' SYSTEM:

Health officials recommend that 'honey-bags' be collected from all households daily; in addition, this assists the collection procedure since a half-full bag is less likely to break. Daily collection, however, is the exception rather than the rule.

There are three methods of 'honey-bag' collection:

1. collection from 45-gallon drums in front of each household, with or without the garbage;

2. collection from the bathroom of each household;

3. collection from the service porch of each household ("2-bucket" system).

1. The householder is supposed to remove the 'honey-bag' from the bucket toilet and place the sealed bag in a 45-gallon drum (used especially for this purpose) in front of his home. Often, the bag is left on the ground, where it is broken by birds, dogs, or children, or where it can freeze to the ground in winter. The presence of 'honey-bags' lying around the settlement is aesthetically unpleasant. If broken, they constitute a danger to health. Removal of 'honey-bag' debris is unpleasant, inconvenient, and difficult. Handling, first by the householder, and then again by the collector, increases the possibility of breakage.

2. A system of in-house collection of 'honey-bags' from the bathroom has been implemented in Cambridge Bay, Arctic Bay, and Frobisher Bay. The 'honey-bag' collector enters the house and removes the 'honey-bag' and pail to the truck. After dumping, a new bag is placed in the pail and the pail is returned to the bathroom. The system is advantageous in that handling of the 'honey-bag' only once by the collector minimizes the chance of breakage. It is convenient to the householder, requiring no conscious actions on his part. 'Honey-bags' are not left around the roads of the settlement where they may be broken. Residents in Cambridge Bay have objected strongly that collection from the bathroom is a serious inconvenience, dirties up the house, and invades their privacy, and about their not having been consulted before the system was placed in operation. The in-house system is somewhat expensive; charges are $2.00 per bag in Cambridge Bay and $1.60 per bag in Frobisher Bay, compared to 40¢ per pickup from drums on the street in Rae.

3. A variant of the in-house from the bathroom collection system is the service porch or "2-bucket" system. Each household has two plastic pails for its toilet. Each morning, the householder ties the top of the bag and places the plastic pail and full bag in the service porch for collection. The second pail, with an empty unused plastic bag inside, is placed in the toilet for use. The collector removes the used bag from the pail and replaces it with a fresh bag. The pail is left on the service porch for use the next day, and the "full" honey-bag is taken to the collection vehicle for disposal. The "2-bucket" system is advantageous in that it minimizes handling of the bag, is clean, and does not leave 'honey-bags' lying around the settlement. The major objection to the in-house system - the invasion of privacy - is not present. The "2-bucket" system requires that all homes have two plastic toilet pails.

There are two methods of 'honey-bag' transport systems. The first system consists of a large flat holding tank with a dumping "ripper chute" with spikes on the interior connected by a chute, and gravity ejection door. The full 'honey-bag' is placed in the ripper chute by the driver and broken on the spikes by an upward hand motion. The contents flow or are sucked into the holding tank, and the ripped bag is placed in a 45-gallon drum especially for this purpose for storage before disposal. In the second system, 'honey-bags' are placed in 45-gallon drums on the back of a tractor-driven cart or pickup truck. The drums with their contents are dumped at the disposal area and re-used. If the necessary equipment can be made available, the use of a ripper chute is recommended.

2.3 TRUCKED SYSTEM FOR HOLDING TANK WASTES:

An alternative to the 'honey-bag' system without going to the expensive piped sewer system is as follows:

Each house has a flat, 250-gallon sewage holding tank installed under an insulated, raised floor in the bathroom. The toilet is mounted directly above. A small amount of water is added for flushing and cleaning by hand ladling. The kitchen sink may also be connected by a pipe to the holding tank. An exterior connection would permit weekly emptying by a vacuum pump collection system similar to that already used on a Nodwell RN75 oil-sewage tanker. A flapper valve between the toilets and the tank reduces odour. The tank must be well insulated to prevent freezing, since, in cold weather, the contents of an insulated tank may freeze and with vacuum extraction, the thin-wall discharge piping may collapse during pump-out.

The capacity provided by a 250-gallon tank is more than adequate for the present weekly output of liquid sewage from an "average household", and adequate for a great increase in water-use habits from the present 1-5 gallon/person/day. In settlements with heavy snow which may block roads and prevent reliable pumpout in winter, this extra capacity is especially important.

Cost data on such an alternative are scarce. Associated Engineering Services Limited (1973) have estimated for Fort McPherson that the capital cost required to install sewage holding tanks and econoflush toilets would be $600 per household. Extensions of gravel pads, where necessary, to permit truck access was estimated at $500 per household. Amortization of $1,100 per household over 20 years at 7-1/2% interest would be about $100 per year, or $20 per person per year, based on an occupancy of 5 people per household. The unit cost

of sewage pumpout (excluding cost of water supplied) was assumed at 2¢ per gallon. At their assumed water consumption of 14 gallons per person per day, the annual operating cost per person per year was $91.00.

On the other hand, Fred Ross and Associates of Cambridge Bay, proposed (Cadario and Heinke (1972)) that the implementation of such a system in Cambridge Bay, with the weekly pumpout of toilet wastes from 60-gallon tanks, would result in a large saving on a long-term contract for labour costs, which would offset the required investment in equipment and facilities. They were apparently prepared to assume all capital costs of such a proposal if they could obtain a long-term contract (5 years) at the same cost now charged for the 'honey-bag' disposal system. However, winter conditions (1971-72) made pumpout unreliable and many of the small capacity tanks overflowed.

The advantages of a system of sewage holding tanks and econoflush toilets are their greater convenience and better hygiene to householders and collectors, and the possible elimination of spillage of other liquid wastes on the ground. The disadvantage is that capital investment is required, which is mostly lost, if in the future utilidors are installed. Serious consideration should be given to such a system as a means to eliminate the 'honey-bag' system in those communities, where for whatever reason it is not likely that a utilidor system will be installed for many years.

In most settlements using 'honey-bags' for toilet wastes, kitchen and laundry wastewater is disposed of by pipe to the ground surrounding the house. With proper drainage and ground conditions, this is adequate as a short-term measure. However, in the long run, another more sanitary means of disposal must be found. Some public health officials feel that this contributes to the occurrence of skin diseases, particularly in children. In addition, it often creates serious inconvenience to householders in the spring when houses often sit "in the middle of a lake".

As soon as tanks are used for toilet wastes, it is recommended that the kitchen sink be connected to the tank for disposal of at least kitchen sink wastes. The tank should be of adequate size for this purpose, and pumpout should be frequent enough to prevent overflow.

2.4 VACUUM SEWERS:

A vacuum sewer uses air pressure instead of gravity as the driving force for wastewater transport. Wastewater is moved in plugs, separated by air gaps, at high velocities through small diameter pipes. The

pressure differential of about one-half atmosphere is created by a central vacuum pump. Specially designed vacuum toilets, valves and a central collection tank complete the system. The advantages of a vacuum sewer system over a conventional gravity system are its ability to transport wastewater horizontally and to a certain extent upgrade, its much lower water useage and, therefore, its more concentrated characteristic, and its lower capital cost. However, length, capacity and lift potential of vacuum sewers are limited by the available pressure differential, which precludes their use in many cases. Averill and Heinke (1973) have provided an extensive review of the system. Pilot installations in arctic regions are now being tested in Alaska (Ryan *et al*, 1972) and may soon be tested in Canada through the Department of the Environment.

In my opinion, vacuum sewer systems will find a sizeable market in northern communities and construction camps. Blackwater (toilet waste only) systems, possibly with connections to include kitchen wastes, are most likely to be constructed where discharge of liquid wastes from bathtubs, laundry, and sinks directly to open ditches, can be tolerated. In other areas these liquid wastes may also need to be conveyed to a treatment facility, either by a greywater vacuum system or by a one-pipe vacuum system. There is, therefore, a need for treatment methods for concentrated wastes (blackwater) as well as more dilute wastes from vacuum sewers.

2.5 PRESSURE SEWERS:

In pressure sewer systems wastes are pumped from the buildings into a pressure main, which continually circulates the wastewater to prevent freezing. Pressure piping can follow the contours of the terrain, and requires smaller diameter piping than gravity sewers. Ahead of the pump at the household a grinding device or a settling tank may be used to prevent blockage of pipes and pumps. An experimental pressure sewer system is installed in a utilidor to serve ten houses at Frobisher Bay, N.W.T. (Heinke (1974), Cooper (1968)). The sewage from the houses is pumped into the circulating sewer line from settling tanks installed underground behind each house. This system was installed in 1967, and although still operating, has required considerable maintenance. I am aware of proposals to install pressure sewers in several northern communities, among them Tuktoyaktuk, but do not know if any have been constructed recently.

2.6 REFUSE COLLECTION SYSTEMS:

Heinke (1973b) reports on refuse collection and disposal methods in the Northwest Territories:

Storage of garbage and refuse at the house is most commonly achieved in the readily available 45-gallon drums. They are, however, difficult to lift by hand. In some communities special raised wooden platforms have been constructed. This has generally been a failure since they are often not used and if used, become an eyesore since they are often not cleaned and covered with much spillage. On the other hand, the 15-gallon metal garbage pails are lighter, but are more easily blown over by wind and do not have the capacity to hold large animal carcasses and other larger types of refuse. Burning of paper and other combustible material at the home garbage drum is usually practised for bulk reduction. Plastic containers are used in some communities, but break in cold weather. In cold weather, garbage will also freeze to the container, making it difficult for the collecting crew to empty them. Paper or plastic garbage sacks have been used recently with somewhat better success. However, if they are put on the ground they will freeze to the ground, with resulting breakage during collection. In some communities special holders fitted with a cover and the sacks hanging free have been used successfully. In spite of organized storage and collection facilities, the appearance of many northern communities suffer from the indiscriminate disposal of garbage, refuse, vehicles, scrap and items of all sorts in yards, roads, beaches, etc. This becomes progressively worse as the winter goes on, though mercifully covered by snow for much of the year.

In most communities there is some organized collection of garbage and refuse, once or in a few cases twice weekly. Vehicles vary in sophistication from tractor-drawn open cart to special garbage packer trucks. Enclosed vehicles prevent garbage from blowing around during collection and are aesthetically more satisfactory. Overall, the collection of garbage is better organized than the storage facilities or the disposal grounds. Garbage crews are responsible in some communities for general street maintenance and cleanup; however, this appears to be done only infrequently. Massive spring cleanups occur in most communities.

Charges for scheduled collection of garbage and its disposal are usually made on the basis of *number* of drums emptied, as for *gallons* of water delivered and sewage picked up, and *number* of 'honey-bags' delivered.

This method of payment places the emphasis on quantity rather than quality of service provided. Since the contract should specify the required frequency and level of service for a settlement's municipal services, which will determine the equipment and labour requirements, the actual quantity under these conditions is not a variable affecting cost of service, and, thereby. payment. Existing charges for drums (normally 45-gallon drums) emptied vary from about 40¢ to $1.00.

I-3 TREATMENT AND DISPOSAL SYSTEMS

3.1 PRESENT METHODS:

With the exception of a few larger communities most do not practise sewage treatment. Those that do generally use lagoons. Dawson and Grainge (1969) and Heinke *et al* (1972) have carried out studies on the Inuvik lagoon and have concluded that lagoons can work in arctic areas if properly designed and operated. Lagoons, however, are generally designed to receive dilute wastes from gravity sewer system. Concentrated wastes should not be dumped into such a lagoon.

Disposal of 'honey-bags' or their contents is now made at a sludge pit-lagoon together with holding tank wastes, or at the garbage dump or at a separate disposal site. With the ripper-chute method of 'honey-bag' collection, when the tank truck is full its contents are dumped by gravity or by ejection pump into the sludge pit. The pit is covered with earth when it becomes full and a new one dug. Liquid effluent may flow from the sludge pit into an adjacent lagoon, if there is one. Ripped, used bags are disposed of separately at the garbage dump. The sludge pit-lagoon disposal method is preferred over other disposal methods. If no sludge pit-lagoon exists 'honey-bags' are dumped separately from dry garbage and in a location where pollution of the water source will not result. The site should be downwind from and out of the settlement. Burning of the contents of 'honey-bags' is extremely unpleasant and is not recommended. The dumping of 'honey-bags' into the sea should be strictly forbidden.

Disposal of collected garbage and refuse in many communities is at an open dump. The dump area should be located far from the water supply to eliminate any possible source of pollution. To remove any aesthetic objections it should be located out of view of the settlement, and downwind, so that unpleasant odours or smoke, from burning at the dump, do not blow over the settlement. It should not be located on the road to the airstrip, to avoid giving visitors an unpleasant first impression of the settlement. A sloping site facilitates dumping operations, and a nearby supply of gravel or sand helps in periodic covering of the garbage. In many communities

this is not possible because of lack of equipment, shortage of gravel or the severe climate. The dump should be fenced, which is mostly not the case now. In some settlements several dump sites are used because of different road access in summer and winter. From an economic point of view, the distances travelled between the settlement and the dump should be as small as possible. However, it cannot be over-emphasized that the dump area should be located far enough from the water source to ensure that water is not polluted by runoff from the dump. The local residents, government officials and health workers should agree that the chosen site is suitable in this regard. The other aspects of dump location are desirable; that the location does not pollute the water supply is essential.

Dumping on ice or in water (ocean) has been practised in the past, but now only in a few small communities where local circumstances may make it tolerable. In general, this method is now prohibited. Sanitary landfill is practised in a few of the more southern communities. The cold climate makes biological degradation so slow, that the value of covering is really only in preventing garbage from blowing around and reducing the danger of disease transmissions through insects and animals. In most cases where sanitary landfill is claimed to be practised, it really is a modified open dump. The most common form of incineration is through open dump burning. Incinerators are used at some industrial camps, but not in communities.

3.2 ALTERNATIVE METHODS:

The alternative methods considered fall into two categories:

- solids handling methods prior to treatment
- treatment and disposal methods.

Solids handling methods are required for 'honey-bags' prior to any possible treatment methods. One improvement in this was seen recently in Greenland (Heinke (1973a)) and is described below. Treatment and disposal methods include anaerobic digestion, chemical precipitation and incineration.

1. 'Honey-bag' Disposal Station:

Disposal stations were inspected at Godthab, which has a bucket collection system, and at Holsteinsborg and Egedesminde, which have bag collection. In all three towns, collection of human waste is carried out daily.

Final discharge of wastes is to the sea, which is considered acceptable in Greenland. All towns larger than 1500 people must have a disposal station built in the next few years. It is a two-storey building, 30' x 20'. It contains a room for unloading and emptying of bags, provisions for thawing frozen bags, oil-fired incinerator for burning empty bags, a winter storage, washroom and changing room for the operator, and a workshop and storage room. The disposal station in Egedesminde, built at a cost of 750,000 Danish Kroner (approx. $125,000), was put into operation in 1972. The populationof Egedesminde is about 3200, but parts of the town are serviced by utilidor. Bags are delivered to the station by a private contractor, who is paid 2.50 Kr/bag ($0.42/bag). One man is employed for the day to day operation of the station. His monthly salary is 1800 Kr. ($300) plus a bonus of 2 Kr. (0.3 cents) per bag in recognition of good effort. He works 64 hours per week from 8 A.M. to 6 P.M. handling approximately 98,000 bags annually, or an average of 270 bags per day. Pickup in Egedesminde takes place directly from the washroom of the houses and consequently only a few of the bags are brought frozen to the station. There are facilities for steaming them (about 8% were frozen last year). Bags are made of strong paper, with a plastic liner. A special clip is used to close them. Empty bags are burned in an oil-fired incinerator. It can only handle 25 bags per hour, and less when bags are very wet. In Holsteinsborg, plastic bags are used and are difficult to burn. The contents of bags are emptied into a collecting tank and discharged through a gravity pipe to the sea below low water level.

Construction of a pilot 'honey-bag' disposal station in one or several communities of the N.W.T. is recommended. It will improve present methods of disposal of 'honey-bags' even without further changes in treatment, occurring at the same time. In addition, Canadian experience with it can be gained prior to implementation of treatment methods for concentrated wastes.

2. Anaerobic Digestion

Application of the anaerobic digestion process for treatment of concentrated wastes is discussed in more detail in Part II of this report. A review of the literature reveals that anaerobic digestion of sewage sludges can function at lower temperatures; however, with reduced rates of digestion so that longer detention times are required. Anaerobic digestion is undoubtedly taking place in sludge pits, however under uncontrolled conditions. The research carried out in the present

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laboratory study has, as one of its objectives, the optimum environmental conditions which must be obtained to treat concentrated wastes satisfactorily and economically. This will include ultimate disposal of anaerobic sludges and further treatment required of the supernatant. For further discussions on this topic see Part II.

3. Aerobic Digestion:

There are substantial possibilities of application of aerobic digestion for treatment of concentrated sewage and sewage sludges in arctic climatic conditions.

Theoretically, the involved reactions are exothermic and may produce more heat than heat losses during the respective treatment. Therefore, the temperatures of liquors under digestion may rise above the temperatures of the inflow material. In turn, these elevated temperatures increase the rate of reaction.

Although there are some examples in Sweden of a successful application of this approach, very little is known about its design parameters and limitations. Even the aeration equipment used for this purpose should be accordingly modified.

4. Physical-Chemical Treatment:

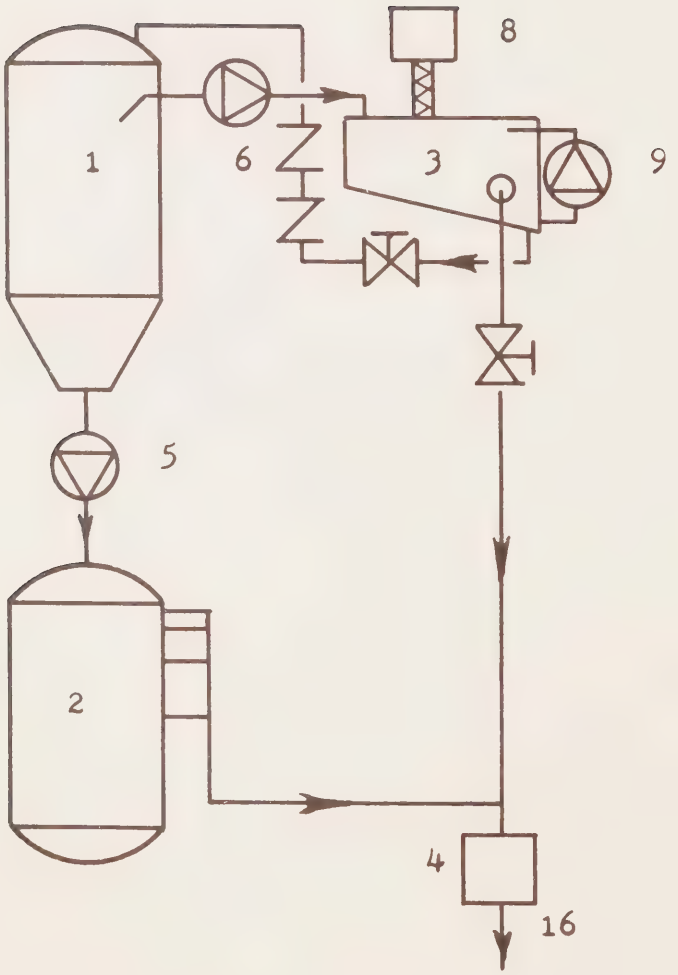
Some experience in physical-chemical treatment of concentrated wastes has been gained in treatment of black water from vacuum sewers by lime precipitation, Jespersen (1973) outlines the system as follows (Fig. 1):

"The black water is collected in the collecting tank (1) (see Figure 1) by the vacuum sewer system. From this tank it is automatically discharged into the lime reactor (3) in fixed batches. In the lime reactor the waste is mixed intensively with lime, $Ca(OH)_2$ from the lime storage tank (8) at a rate of six pounds per 100 gallons (400 flushes). The circulating pump (9) starts immediately sucking the lime mixed sewage from the bottom of the lime reactor and throws it at a high velocity against the upper walls of the reactor. In larger installations air is blown in at the bottom of the lime reactor.

During the circulation time (approximately 30 minutes) the pH value increases to above 12. With this high pH value the urea compound (NH_2CONH_2) in the liquid reacts with water to form ammonia (NH_3) and carbon dioxide (CO_2). After the liquid waste has been mixed with lime the batch is allowed to settle for 30 to 40 minutes, during which period phosphorus is precipitated and at the same time strong flocculation of suspended and colloidal particles occurs in the liquid which forms a sediment

FIGURE 1 BLACK WATER TREATMENT PLANT

(after Jespersen 1973)



1. Collecting Tank
2. De-watering Tank
3. Lime Reactor
4. Ammonia Expellor
5. Sludge Pump
6. Sewage Transport Pump
8. Lime Dosing Tank
9. Circulation Pump
16. Treated Black Water

on the bottom of the lime reactor. If no grey water has to be treated the black water effluent goes to the receiving water body through an ammonia expeller (4) and a pH reducer. The sludge which has settled in the lime reactor is either pumped to a sludge bed or taken back to the collecting tank by vacuum. Sludge from the dewatering tank (2) is fluffy, has a high lime content and is odour-free. It is periodically removed by scavenger truck and can be used as fertilizer.

In the treated black water effluent the original quantity of phosphorus is reduced by approximately 99%, nitrogen by 75% and BOD by 70%. At the same time, nearly all pathogenic bacteria and viruses have been killed due to the high pH value. In some areas re-carbonation to decrease the high pH value of the effluent must be done."

Experience with lime precipitation of black water has been gained in several European countries, notably in Denmark. Canadian application, at the research pilot plant and finally full scale installation should be carried out in conjunction with vacuum sewer installations. Lime treatment of 'honey-bag' wastes, with or without prior digestion, by anaerobic or aerobic processes, should be investigated.

Deans and Heinke (1972) report on another chemical treatment method, the Elsan Yarrow System (Fig. 2).

"It was originally designed to treat shipboard wastes; however, three land installations are now in operation, two in Great Britain and one at the supplier's plant at Port Colborne, Ontario. These are compact, factory assembled treatment units designed to service the kitchen and personal wastes of 25 to 120 people. The largest unit is about 10 feet long, 6 feet wide and 6 feet high. Additional space would be required for the control panel and pressurized supply tank. The unit employs chemicals with the trade names E.C. 1, a chlorine compound, and E.C. 2, which contains sodium hydroxide, to reduce all sewage, paper, and vegetable matter from the water closets or drains, to a completely sterile liquid of acceptable odour and colour. This liquid is claimed to be acceptable for recirculation as flushing water.

The Elsan Yarrow Unit may be charged with either salt or fresh water. The operation of this unit is as shown in the line diagram (Fig. 2). The E.C. 1 chemical, in tablet form, releases chlorine in the pressure breakdown tank which improves the colour and odour of the wastes. The wastes then pass through a comminutor where they are further broken down, and then to the chemical treatment tank. The chemical E.C. 2, in flake form, is added in this tank. These flakes which contain sodium

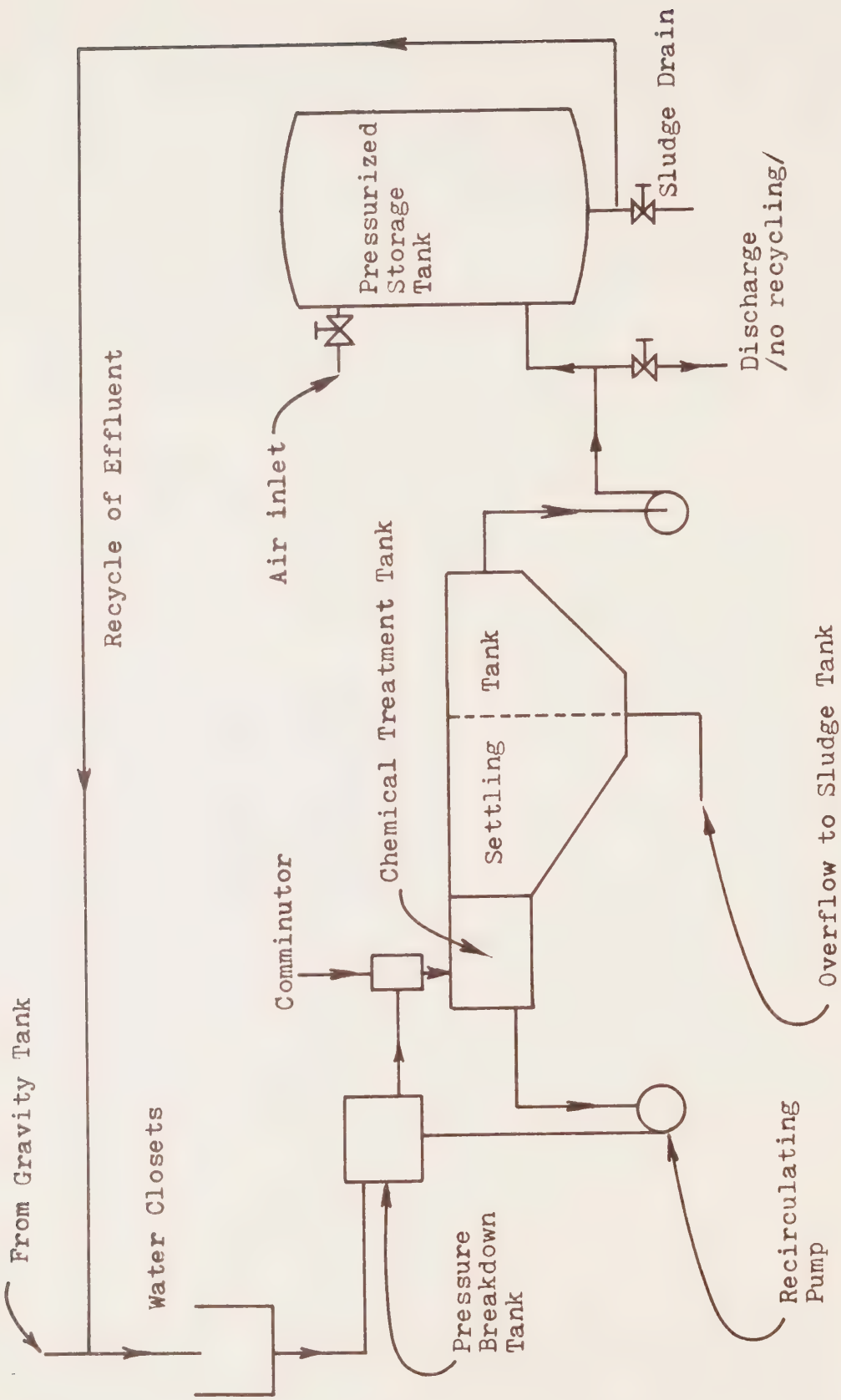


FIGURE 2 FLOW DIAGRAM - ELSAN YARROW CHEMICAL TREATMENT
(after Deans and Heinke (1972))

hydroxide, further break down the solids and ensure stability of the effluent.

This type of unit may have application in recreational or industrial camp sites, for military field use or for specific buildings or institutions within a community. The compact size of this unit permits adaptation for installation in transportable or mobile units. Technical supervision of the plant operation would have to be available."

5. Incineration:

Incineration is a process where either all liquid and solid wastes are burned when mixed with a combustible fluid or where concentrated wastes or sludges are reduced to an inert ash by burning with a fuel, or by an electrical element. Alter (1969) reported that the first method has yet to be perfected for general use. A survey by Deans and Heinke (1972) of manufacturers and suppliers indicated that no commercial models were available in 1971. However, developments were being worked on and may have resulted in commercial units by now. Further investigation following this preliminary report needs to be done.

The latter method has been applied to concentrated sewage, concentrated black water wastes and sludges. Baumgartner (1960) reports on the use of an oil-carriage sewage incineration system at remote air force sites in Alaska. Jespersen (1973) reports on incineration of black water. If oil or gas is readily available, incineration of the black water is often both technically and economically feasible for small communities. Most incinerators in Scandinavia (Paccanora-hammer, Atlas Denmark, etc.) use 0.5 to 0.7 litres of heavy fuel oil per litre of waste. The advantages are:

1. Low installation cost.
2. No sludge handling problems.
3. Extra heat for numerous purposes available.
4. Possibility of pyrolyzing or burning garbage from the household.

Deans and Heinke (1972) report on the possible application of a commercial unit for toilet waste, sludges or refuse:

"A representative unit which is commercially available for the burning of concentrated human wastes is manufactured by Garret Industries, Rexdale, Ontario. This unit was originally developed for the incineration of chemically treated human wastes from portable military field installations. Units for commercial use would be modifications of this military unit.

The Garret incinerator has the capacity to burn the toilet and solid wastes (garbage) generated by 250 people per day, using either diesel oil, gasoline, natural gas or manufactured gases. The wastes are burned in batches, equivalent to that generated by 80 people, in 6 to 7 hours at a temperature of 1600°F. Fuel consumption would be 1.1 U.S. gallons of diesel fuel per hour. The electrical power required for the blower and controls is 350 watts. Cost for this unit would be about $15,000.

The incineration of waste sludges would have the advantage of complete destruction of the wastes. Both sludges and general garbage could be burned in the unit. Small units, like the one described, can be operated and maintained with a limited amount of technical knowledge and skills.

Disadvantages of the incineration process include high capital cost, requirements for fuel and electrical power, and odours if the unit is improperly operated or maintained. Local incinerator requirements may also be a problem in the operation of the particular unit described. For example, the Ontario Air Management Branch of the Department of Energy Mines and Resources, require that an incinerator which burns Type 4 wastes have minimum combustion chamber temperatures of 1800°F and stack temperatures of 1600°F. Type 4 wastes include materials in which pathogenic bacteria might be present (Air Management Branch Department of Energy and Resources Management, 1970)."

Substantial information is available on a small incinerator for refuse disposal at the Murphy Dome Air Force Station in Alaska (Smith and Straughn (1971)).

The recent large increases in costs of energy and in particular of oil, require re-evaluation of the possible economics of incineration for destruction of toilet wastes and refuse. Insufficient work has been done as part of this report to come to any firm conclusions.

REFERENCES

Alter, J. (1969)
Sewerage and Sewage Disposal in Cold Regions. Monogr. III-C5b, Cold Reg. Sci. & Eng., Hanover, N.H.

Associated Engineering Services Ltd. (1973)
Solid Waste Management in the Canadian North, Rep. Environ. Prot. Serv., Environ. Canada, Ottawa.

Averill, D.W. and Heinke, G.W. (1973)
Vacuum Sewer Systems for Northern Applications, Proc. Symp. Wastewater Treat. in Cold Clim., Saskatoon.

Baumgartner, D.J. (1960)
Water Supply and Waste Disposal Problems at Remote Air Force Sites in Alaska, Proc. 11th Alaska Sci. Conf. 91

Cadario, P.M., and Heinke, G.W. (1972)
Manual for Trucking Operations for Municipal Services in Communities of the Northwest Territories, Publ. Dept. Civ. Eng., Univ. Toronto.

Cooper, P.F. (1968)
Engineering Notes on Two Utilidors, Technical Notes -1, North. Sci. Res. Group, Dept. Indian Affairs and North. Dev., Ottawa.

Dawson, R.N. and Grainge, J.W. (1969)
Proposed Design Criteria for Wastewater Lagoons in Arctic and Sub-Arctic Regions, J. Water Pollut. Control Fed., 41, 237.

Deans, B. and Heinke, G.W. (1972)
Household and Community Waste Disposal Systems for Northern Communities, Publ. Dept. Civ. Eng., Univ. Toronto.

Fair, G.M., Geyer, T.C., and Okun, D.A. (1968)
Water and Wastewater Engineering, Vol. 2, John Wiley and Sons Inc., New York.

Hawk, P.B., Oser, B.L., and Summerson, W.H. (1937)
Practical Physiological Chemistry, 12th ed., The Balkinston Co., Toronto

Hanks, T.G. (1967)
Solid Waste/Disease Relationships - A Literature Survey Publ. Public Health Serv., U.S. Dept. of Health, Education and Welfare, Cincinnati.

REFERENCES (CONT'D)

Heinke, G.W. (1974)
Report on Municipal Services in Communities of the Northwest Territories, Dept. Indian Affairs & North. Dev., Publ. No. QS-1323-000-EE-A1, Ottawa.

Heinke, G.W. (1973a)
Report on Environmental Engineering in Greenland and Northern Scandinavia, Dept. Civ. Eng., Publ. No. 73-05, Univ. Toronto.

Heinke, G.W. (1973b)
Solid Waste Disposal in Communities of the Northwest Territories, Rep. Environ. Prot. Serv., Dept. Environ., Ottawa.

Heinke, G.W., Miyamoto, H., and Jacobsen, N. (1972)
Evaluation of a Sewage Lagoon at Inuvik, N.W.T., Publ. Dept. Civ. Eng., Univ. Toronto.

Ikeda, I. (1972)
Experimental Study on Treatment of Night Soil by the Wet Air Oxidation Process, Water Res., 6, 967-979.

Iwai, S., Honda, A., and Chong, C.Y. (1962)
Experimental Studies on High Rate Digestion of Night Soil. Mem. Fac. Eng., Kyoto Univ., Vol. XXIV, Part 3.

Jespersen, F. (1973)
Vacuum Sewage Transport and Treatment in Rural Areas in Denmark, Proc. Symp. Wastewater Treat. Cold Clim., Saskatoon.

Olsson, E., Karlgren, L. and Tullander, V. (1968)
Household Waste Water, Rep. Natl. Swedish Inst. Build. Res., Stockholm.

Painter, H.A. and Viney, M. (1959)
Composition of Domestic Sewage, J. Biochem. & Microbiol. Tech. Engg., 1: 143-162

Ryan, W.L., Crum, J.A., and Rogness, D.R. (1972)
Sanitation Facilities Construction Branch, Alaska Area Native Health Service, Depart. Health, Educ. & Welfare, U.S.A. (Personal Communication) 1972-1973.

Smith, D.W. and Straughn, R.O. (1971)
Refuse Incineration at Murphy Dome Air Force Station, Arctic Health, Educ. & Welfare, Fairbanks, Alaska.

Spector, W.S. (1956)
Handbook of Biological Data, W.B. Saunders & Co., Philadelphia - London

II-1 THE ANAEROBIC DIGESTION PROCESS

1.1 A BRIEF REVIEW:

Anaerobic digestion, as a biological process in waste treatment, has been practised since the beginning of the twentieth century. Imhoff (1906) was one of the first to use plants which separated solids from mixed sewage. The settled sewage was then digested in the lower compartment of the Imhoff tank. Since those early days, anaerobic digestion has gained importance primarily as a means for treating the solid organic matter contained in sewage, but also for industrial wastes carrying high concentrations of dissolved organic matter.

Anaerobic digestion, a process also occurring widely in nature, can be defined as a biological process, in which complex organic matter is converted to methane and CO_2 in the absence of oxygen. The stabilization of organic matter in waste is mainly brought about by bacterial metabolism which converts the complex organic molecules into stable end products. A portion of the organic matter is synthesized into new cell protoplasm, while a further portion is oxidized as a source of energy. Unlike aerobic oxidation, the anaerobic conversion yields relatively little energy to the micro-organisms. Thus, their rate of growth is slow and only a small portion of the waste is converted to new microbial cells, the major portion of the degradable waste being converted to methane gas. Such conversion to methane gas represents waste stabilization since methane gas is insoluble in water and escapes from the waste stream. It can be collected and burned to CO_2 and water for heat. As much as 80 to 90% of the degradable organic matter of the waste can be stabilized in anaerobic digestion by conversion to methane gas, even in a highly loaded system. This is in contrast to aerobic systems, where only about 50% of the waste is actually stabilized even at conventional loading (McCarty (1964)).

Anaerobic digestion is usually considered to be a two-stage process consisting of acid-formation (liquefaction) and gas-formation (gasification). At least two large, physiologically different, bacterial populations must be present for the overall conversion of organic matter to methane and CO_2 to occur. In the first stage, a heterogeneous group of micro-organisms convert proteins, carbohydrates and lipids mainly into fatty acids by hydrolysis and fermentation (McCarty *et al*, (1963)). In the second stage, the end products of the metabolism

of the micro-organisms of the first stage are converted to methane and CO_2 by strict obligate anaerobic bacteria called methanogenic (methane-formers) bacteria.

Several investigators in the past suggested that the bacteria involved in the "acid-formation" stage are predominantly facultative, with a few obligate anaerobes (McKinney (1962), McKinney *et al* (1958), McCarty *et al*, (1962)). This concept was more recently questioned by Toerien *et al* (1967) who were of the opinion that aerobic and facultative anaerobic bacteria account for only a small proportion of the total bacterial population of anaerobic digesters. These investigators (Toerien & Siebert (1967)) developed a method based on the cultivation methods used in rumen microbiology and used this new method to enumerate obligate anaerobic acid-forming bacteria in digesters. The anaerobic counts were usually 100 or more times greater than the aerobic counts (Toerien *et al*, (1967)). The suggestion of McKinney (1962) that acid-formation is mainly carried out by facultative bacteria seems to be incorrect in the light of these results.

The methane bacteria and their characteristics which are responsible for the majority of the stabilization in the second phase in anaerobic digestion, are poorly defined, although studies on methane bacteria have been carried out for many years. Until recently the techniques for the enumeration of methane bacteria were very poor. However, good methods based on those of Hungate (1950) which have been used in rumen microbiology, are now available. These methods formed an interesting approach to the study of methane bacteria in sludge digestion (Mylroie & Hungate, 1954). It is unfortunate that further work does not appear to have been carried out along these lines except that of Siebert & Hatting (1967).

1.2 ANALYTICAL TECHNIQUES FOR CONTROL AND CHARACTERIZATION OF ANAEROBIC DIGESTION:

The major factors determining the nature of a specific digester are the substrate composition and loading, the temperature of operation, the design of the digester tank, the mode of operation and the source of the inoculum of micro-organisms required to digest the substrate (Kotze *et al*, 1969).

Before it is possible to control anaerobic digestion efficiently it is necessary to characterize a well-operating digester. No single factor (parameter) can be used as a control measure of the process of

anaerobic digestion as the degradation of organic matter to methane and CO_2 is brought about by a heterogeneous microbial population. Various factors affect digestion and a number of "general" parameters such as pH, alkalinity, volatile acid content, solids and volatile solids content, COD of feed and effluent and rate and composition of gases produced are normally used to control anaerobic digestion (Pohland (1962), Hatting *et al* (1967)). These investigators indicated that the above named "general" parameters were not sufficient to describe anaerobic digestions and thus biological parameters were developed by them to assess the state of biological activity.

1.3 LOW TEMPERATURE ANAEROBIC DIGESTION:

The reactions taking place in an anaerobic digester result from the activity of the heterogeneous bacterial population. The effect of temperature on the process as a whole is therefore a reflection of the behaviour of the bacteria at different temperatures. Buswell (1957) reported that production of methane could be achieved from $0^{o}C$ to $55^{o}C$. However, generally, anaerobic digestion in the mesophilic temperature range ($20-45^{o}C$) with an optimum at about $37^{o}C$ is practised. This is in large part due to the high energy requirements for temperature maintenance. Thermophilic temperatures often bring about more efficient digestions but control of temperature seems to be the greater problem. Sudden temperature changes are detrimental to anaerobic digestion (Buswell, 1957).

Little information is available concerning low temperature anaerobic digestions. Rudolfs (1927) reported studies on unseeded sewage sludge at temperatures of 10, 18, 24, 29.5 and $35^{o}C$. About 360 days retention time was required at $10^{o}C$ compared to 61 days at $27^{o}C$ to $28^{o}C$. Fair and Moore (1934, 1937) report digestion times at $10^{o}C$ of 4 to 5 times that required at $25^{o}C$, and digestion times of nearly 8 times that required at $25^{o}C$ when operating at $5^{o}C$. Interestingly, these longer required digestion times at lower temperatures do not agree with those predicted by thermodynamic considerations. However, micro-organisms do not always follow thermodynamic laws. Zeller (1928) reported that freezing was not disruptive to the anaerobic process if the reactor is later returned to its original temperature, in that case $20^{o}C$. Recently, there has been little investigation of the anaerobic process at low temperature. O'Rourke and McCarty (1967) reported on studies at 25 and $15^{o}C$ on the digestion of sewage solids. McGhee (1968) conducted studies on digestion of sewage solids at a temperature of $25^{o}C$ with continued methane production and destruction of total and volatile solids.

From these studies it appears that anaerobic digestion can function at lower temperature; however, with slower rate of digestion requiring longer detention times. McGhee (1968) concluded from his studies that the anaerobic process at low temperature is equivalent to that at high temperature and is not dependent upon the generation of a specialized population of psychrophilic bacteria. The normal sewage bacteria continue to function at low temperature, though at a much reduced rate. Since his studies were not extended to determine the psychrophilic population, the statement should be accepted with reservation.

II-2 EXPERIMENTAL SETUP AND ANALYTICAL METHODS

2.1 EXPERIMENTAL SETUP:

To simulate the present practice of dumping of 'honey bags' into a sludge pit constructed in permafrost, an anaerobic laboratory sludge pit, described below, was constructed. It is being operated so far at a temperature of -5°C (21°F) which is the approximate soil temperature at a depth of about 3-5 m. (10-15 ft.) underneath undisturbed tundra under winter conditions. (Edwards, (1974) Private Communication). In order to be able to compare results at such low temperatures to those achieved at higher temperatures a conventional anaerobic batch reactor is operated at 10°C concurrently.

1. Anaerobic Pit

The laboratory anaerobic pit consists of a wooden box 122 x 92 x 92 cm. (4 x 3 x 3 ft.). In the centre, a 61.0 cm. (2 ft.) long plastic container (dia. 38.0 cm.) having a volume of 68ℓ (15 gal.) was placed. In order to simulate the permafrost conditions, the box was filled with loam soil in such a way that the plastic container was surrounded by a minimum of 30.5 cm. loam soil. To facilitate the introduction of the waste and collection of the mixed liquor from the pit, a 30.5 x 30.5 x 30.5 cm. (1 x 1 x 1 ft.) lid box was prepared and fitted at the top of the plastic container. (Figs. 3 and 4). The anaerobic pit is operated at -5°C temperature in a walk-in incubator.

The concentrated waste is introduced at the rate of 5-7 litres per week.

2. Anaerobic Batch Reactor

A 20-litre glass bottle is used for the laboratory anaerobic batch reactor. This unit is operated at +10°C in an incubator. The bottle was filled with 17 litres of concentrated waste, and was closed with a rubber stopper and sealed. Gas was removed through glass tubes

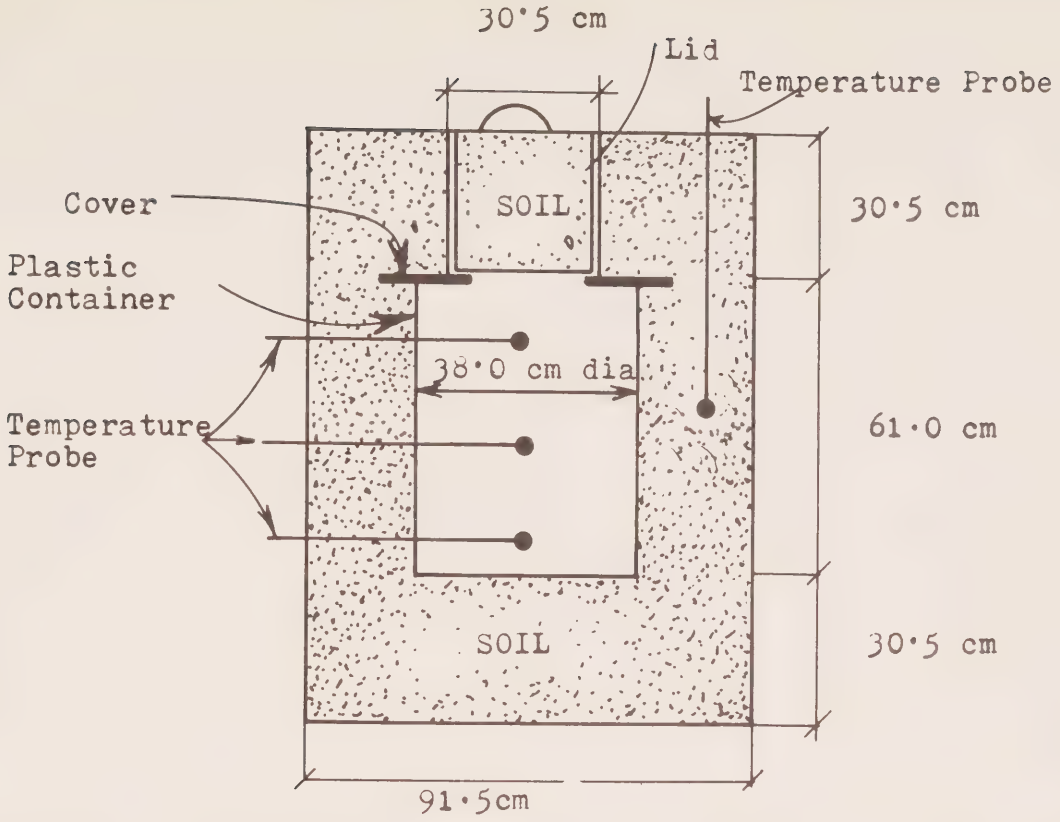


FIGURE 3 DIAGRAM OF THE LABORATORY ANAEROBIC PIT AT -5°C

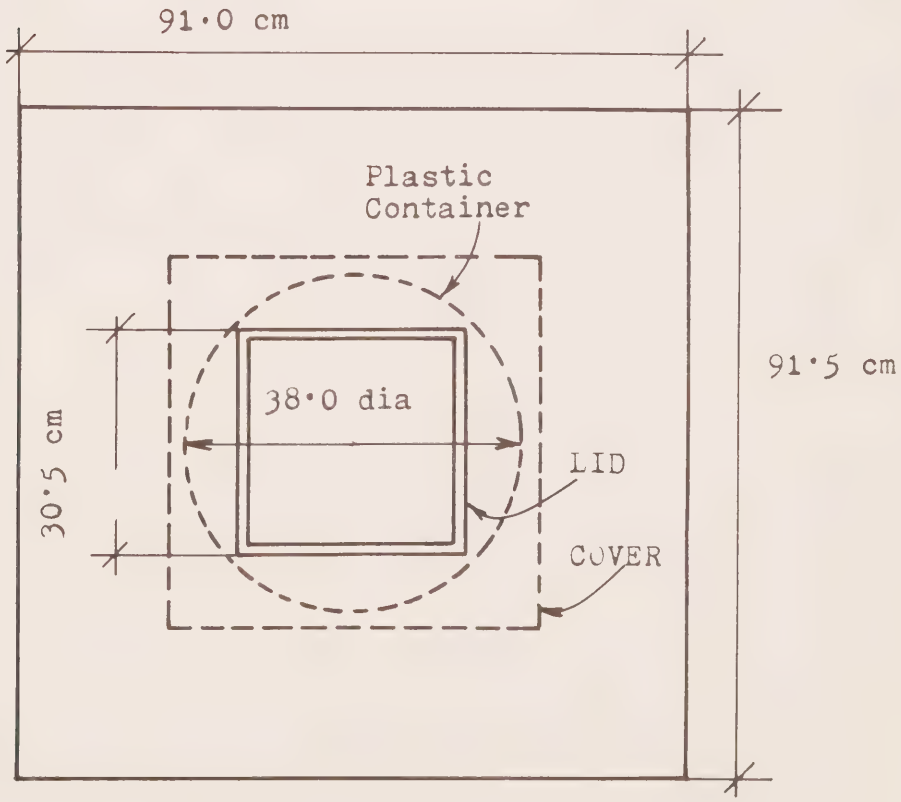


FIGURE 4 PLAN VIEW OF THE LABORATORY ANAEROBIC PIT

inserted in the stopper. Mixed liquor was withdrawn through a tube with the help of a pump. Gas was delivered into one litre graduated bottles containing an acidified solution saturated with common table salt. The acidification and saturation with NaCl insures the insolubility of the gases produced (Fig. 5).

3. Collection and Handling of Human Waste

The study ran into several difficulties in the early stages, especially because of the difficulty in obtaining human body waste free of inhibitors, in a metropolitan area. These difficulties delayed the start of laboratory investigations for several weeks. Local sanitation firms were contacted for the supply of the inhibitors-free human waste, but they were reluctant to do so. However, one firm agreed to cooperate, but their efforts had to be abandoned after only one collection, because only 5.0 litres of waste free of chemical inhibitors was thus procured in two weeks' time. Finally, one firm agreed to lend us a portable toilet. It was brought to the university laboratory in the month of January, 1974, and is being operated since then. About 2-5 persons were expected to use the portable toilet every day. This number, however, dropped to one person per day on several occasions.

Both faeces and urine were collected and the amount measured. This ranged from 0.5 to 3 litres per day, depending upon the number of persons using the toilet. The waste was stored in a bottle for a week at $-5^{o}C$. Before being transferred to the pit, the waste was thawed at room temperature overnight. Waste characteristics, such as pH, alkalinity, COD, total and volatile solids, total nitrogen, NH_4-N, total PO_4 and calorific values were determined on the contents of the bottle, before transfer to the pit.

2.2. ANALYTICAL METHODS:

1. Sampling and Replication

An estimate of the precision of the procedures involved in sampling, analysis and replication of analyses was needed, since the waste is of very high strength. Parameters which could affect replicate samples were tested: volume of sampled waste, homogenization of the waste, dilution of the waste. The following procedure, which is considered adequate for the work, was evolved:

All samples of wastes are collected weekly, homogenized by Waring Blender. The analyses of samples for both physico-chemical and bacteriological tests were commenced within a few minutes of sampling except for the

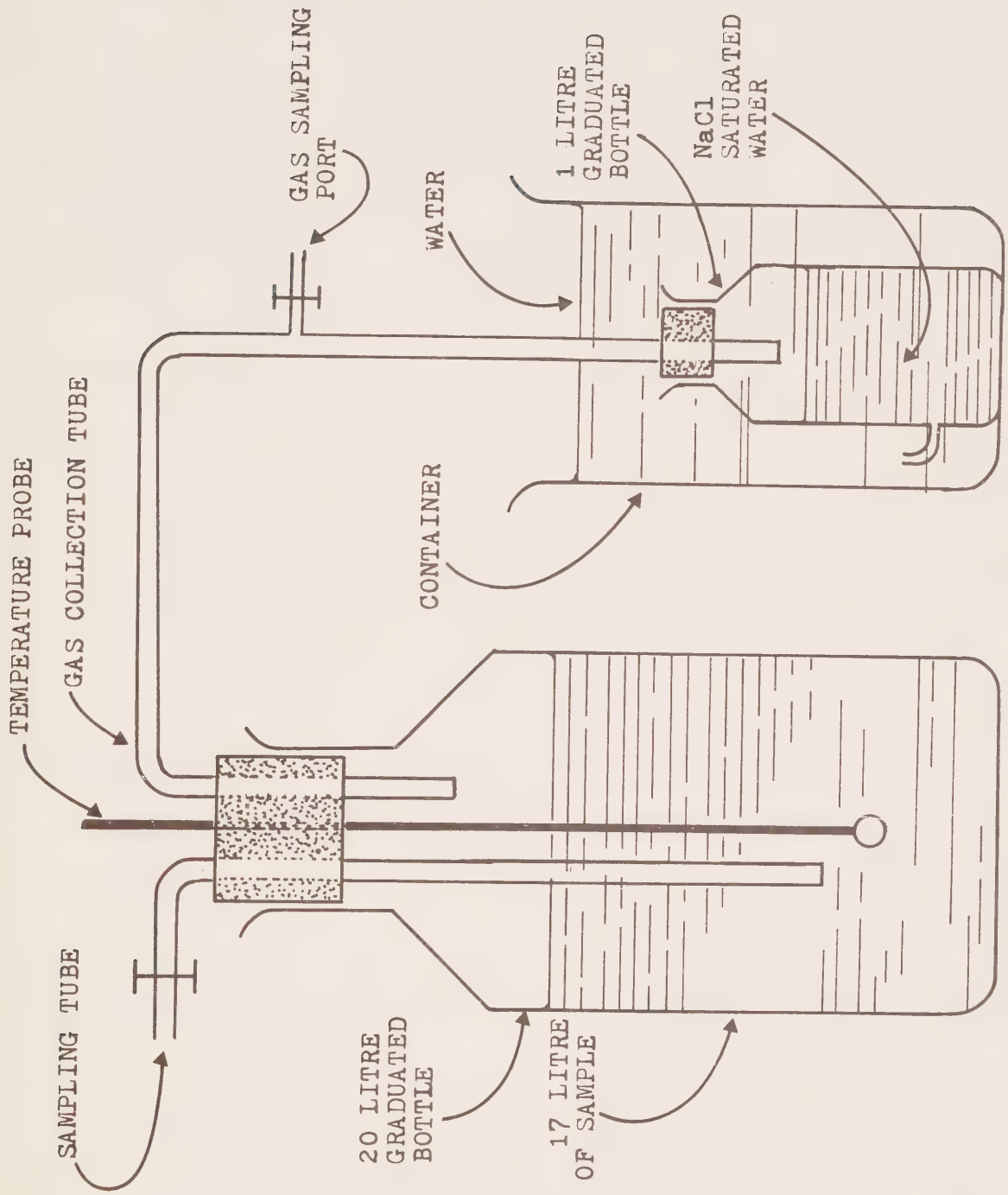


FIGURE 5 DIAGRAM OF THE LABORATORY ANAEROBIC BATCH REACTOR AT 10°C

samples collected from the anaerobic pit, where the delay extended 1-2 hours due to the need for thawing of the samples. The medium delay between sampling and plating for bacteriological analyses was 60 minutes.

2. Physical and Chemical Methods

pH:-

pH was measured on all samples withdrawn from the units as well as the waste collected from the toilet. It was measured as rapidly as possible to minimize the change due to loss of CO_2.

Alkalinity:-

Total alkalinity was measured regularly by titration with 0.1 NH_2SO_4 to a pH of 4.5. The samples were diluted to 100 times and 25 ml. of the diluted sample was normally used for titration.

Chemical Oxygen Demand (COD):-

COD, together with volatile and total solids, was used as an operational parameter. COD measurements were made on 10 ml. of diluted samples according to Standard Methods (1971).

Solids:-

Solids, both total and volatile, were measured for both anaerobic pit and anaerobic batch reactor mixed liquors. Later on, dissolved solids and dissolved volatile solids were also measured on centrifuged supernatant.

Nitrogen:-

Both NH_4-N and organic nitrogen were determined by Kjeldahl procedure as described in Standard Methods (1971).

Phosphorus:-

Total phosphorus in samples was determined according to the method described by Heinke (1969), using aminonaphtholsulfonic acid and an auto analyzer.

Calorific Values:-

An oxygen bomb calorimeter manufactured by Parr Instrument Co. Inc. was used for determining calorific values. The determinations were made on 1.0 gm. of

oven dried (105°C) waste material. The results are reported in terms of cal/g. of oven dried weight and ash free oven dried weight.

3. Bacteriological Methods

The total number of viable aerobic and anaerobic bacteria and fecal streptococci were determined by the dilution plate method. Ten-fold dilutions were prepared in physiological saline, and 1.0 ml. aliquots of the desired dilutions were plated with 10 ml. aliquots of appropriate fluid agar (50°C). For each medium, 3-4 dilutions of each sample were plated in duplicate. The plates thus prepared were incubated in the dark for 7 days for mesophilic bacteria at 20°C, for 4 weeks for psychophilic bacteria at 0°C, and for 48 hours for fecal streptococci. For anaerobic bacteria plates were incubated at 20°C and 10°C in anaerobic jars.

Total Bacterial Count:-

The bacterial medium used for total bacterial count was the nutrient agar described by the Society of American Bacteriologists (1957) supplemented with 0.1% glucose at pH 7.4. Actidione was added to the fluid agar (50°C) just before plating to give a final concentration of 0.1%. The actidione stock solution (1.0%) had been previously sterilized by autoclaving for 10 min. at 121°C and 20 lb. pressure. Preliminary investigations had shown that all waste supplies contained large numbers of fungi, which suppressed the growth of bacteria on the plates. Since the wastes were stored at -5°C prior to transferring to the units, and fungal spores are more resistant to freezing than most bacteria, the large number of fungi observed is not surprising. Because of the large numbers of fungi, the incorporation of actidione, a fungicide, was considered essential.

Obligate Anaerobic Bacterial Count:-

We are attempting to count obligate anaerobic bacteria using the new method developed by Toerien & Siebert (1967) in the present study. This method includes the use of the roll-tube technique. A small portion of the material under test is introduced into melted nutrient agar contained in a small, specially designed, bottle which is held in a horizontal position in an electrically driven spinner. The spinner is constructed of heavy gauge mild steel and holds seven bottles in stainless steel spinner heads driven by a 1/2 h.p. motor. As the bottles rotate in the spinner they are bathed in cold water contained in a cooling trough. This causes the melted and inoculated agar to set within one minute in the form of a thin film. The bottles are then incubated at a suitable temperature. After incubation the colonies which develop on the thin agar film are counted.

Unfortunately, the roll-tube spinner is not available in Canada, so we had to get it made in our workshop. This equipment is ready for use now and will be used from now on.

Methane-Forming Bacterial Count:-

In the present study an attempt will be made to enumerate the methane bacteria by MPN method developed by Siebert & Hatting (1967). This work will be started when the reactors reach the methane-formation phase.

Test for Indicator Organisms:-

Tests for coliforms and fecal streptococci (enterococci) were conducted regularly to determine the bacteriological safety of the treated waste. Although the validity of these indicators is questioned for various reasons, especially in cold regions, these are the best ones we have at hand. Some data is available from cold regions on coliforms and other fecal indicators in sewage lagoons (Miyamoto 1972), rivers and lakes (Boyd and Boyd 1967); little is available on toilet waste disposed of in 'honey bags'. The literature contains several references to the use of other indicator organisms such as *Clostridium perfringenes, Pseudomonas aeruginosa;* due to lack of time, these were not included in this study. However, we are planning to use these indicators in the future.

Coliforms:-

In the preliminary experiments McConkey Agar was tried for total coliform plate counts, but found to be unsuitable, because the number of coliform bacteria reduces tremendously due to freezing of the wastes at $-5^{o}C$. Furthermore the unusual nature of the sample made it difficult to identify bacterial colonies on the plates. Therefore, coliforms were estimated by MPN method in accordance with Standard Methods (1971).

Fecal Streptococci (Enterococci):-

Fecal streptococci were determined by the pour-plate technique using M-Enterococcus agar according to Standard Methods (1971).

II-3 RESULTS AND DISCUSSIONS

The results and discussion relate to:

1. Waste (Feed) put in the anaerobic pit and the batch anaerobic reactor.

2. Pit mixed liquor.

3. Batch reactor mixed liquor.

The results for both anaerobic pit and batch anaerobic reactor are discussed with respect to the following in the order indicated:

3.1 Physical-Chemical Results:

1. Volume and the composition of the Human Waste

2. Temperatures

3. pH and alkalinity

4. Solids -- total, volatile, dissolved and suspended

5. COD

6. Nitrogen

7. Calorific value

Bacteriological Results.

1. Volumes and the Composition of the Human Waste:-

The volume of human waste was dependent on the number of persons who used the toilets, their diet, the frequency of excretion, and the purpose. Sometimes the toilet was used only for urine excretions. The volumes of the waste transferred to the anaerobic pit during the different weeks are shown in Table IV.

TABLE IV

VOLUME OF WASTE INPUT INTO THE ANAEROBIC PIT

MONTH/WEEK	No. of Days	Waste-Input Litres	Average Waste Produced litres/day
Feb. - 2nd week	5	7.5	1.5
Feb. - 3rd week	5	5.0	1.0
Feb. - 4th week	5	6.5	1.3
Mar. - 1st week	5	5.0	1.0
Mar. - 2nd week	5	6.0	1.2
Mar. - 3rd Week	5	7.0	1.4
TOTAL & AVERAGE:	30	37.0	1.23

Daily rate of waste input to the batch anaerobic reactor was not determined. However, since there was little change in the number of persons using the toilet, the rate of waste input to the batch anaerobic reactor was not much different from the rate of waste input to the anaerobic pit.

Only few samples (six) have been analyzed to date and the results are shown in Table V. In order to compare the results obtained in this study, data taken from the literature (Table I) and converted to comparable units (mg/l) are shown in Table VI. By comparing Tables V & VI, it can be seen that Total solids (75,850-85,030 mg/l) and COD values (11,220-134,820 mg/l) in this study (Table V) are considerably higher than those reported (Total Solids - 63,077 mg/l, COD - 81,538 mg/l) in the literature (Table VI).

TABLE V

COMPOSITION OF HUMAN WASTE - RESULTS OF ANALYSIS

Date	pH	Alk. mg/l $CaCo_3$	Mixed Waste COD mg/l	Total Solids mg/l	Total Volatile Solids mg/l	Dissolved Solids mg/l	Dissolved Volatile Solids mg/l	Mixed Waste: Nitrogen			Phosphorus as PO_4 mg/l.	Calorific Value Cal/g	Centrifuged Supernatant COD mg/l.
								TKN mg/l	NH_4-N mg/l	Organic-N mg/l			
12-2-74	8.80	-	110,880	79,980	63,415	53,620	44,760	7,580	3,700	3,880	3,500	4,340	44,880
19-2-74	8.85	16,400	134,820	83,250	66,410	38,720	27,120	8,230	3,530	4,700	3,400	4,260	-
26-2-74	8.90	17,800	110,220	75,850	59,170	37,650	25,450	8,180	3,920	4,260	4,000	-	46,990
5-3-74	8.76	15,000	125,630	83,440	67,740	41,070	29,660	8,620	4,370	4,260	4,250	4,380	54,910
12-3-74	8.85	17,000	121,700	85,030	67,220	43,310	30,340	8,400	4,370	4,030	3,500	4,330	61,280
19-3-74	8.85	13,600	102,080	75,560	56,680	36,600	21,980	9,520	4,060	5,520	-	-	42,240
Mean	8.84	15,960	120,650	81,510	64,790	42,870	31,470	8,150	3,980	3,790	3,730	4,330	52,010
Std. Deviation ±	± 0.04	± 1,550	± 10,380	± 1,160	± 3,560	± 6,390	± 7,690	± 430	± 380	± 120	± 320	± 40	± 7,530

TABLE VI

COMPOSITION OF HUMAN WASTE - LITERATURE VALUES

(Taken from Table I)

Total Solids	=	63,077 mg/l
COD	=	81,538 mg/l
Total Nitrogen	=	10,538 mg/l
Total Phosphorus	=	1,154 mg/l

These higher values are probably due to the addition of tissue paper in the waste collected from the laboratory toilet. Addition of tissue paper was considered essential in order to represent the actual waste collected in 'honey bags'. Total nitrogen values (7,580 mg/l - 9,520 mg/l) obtained in this study (Table V) are slightly lower than the literature values (10,538 mg/l). This difference may be attributed to the fact that the waste collected was contributed during working hours (from 9 a.m. to 5 p.m.). Since most of the nitrogen in human body waste comes from urine (Table 1), the low values may be due to the absence of the urine excreted by the persons using the toilets in the early morning. To check on this hypothesis, total nitrogen was determined in the urine excretions of one person starting from early morning (8:00 a.m.) until 5:00 p.m. The results are shown in Table VII. Considering the nitrogen values (14,000 mg/l) in the urine sample excreted early morning, the explanation for low nitrogen values obtained in the waste appears to be correct. The values of total phosphorus in our waste are in agreement with that of literature values.

TABLE VII

VOLUME & TOTAL NITROGEN IN URINE EXCRETED BY ONE PERSON DURING WORKING HOURS

(8:00 a.m. to 5:00 p.m.)

Time	Total-N mg/l.	Volume Urine Excreted ml.
8:00 a.m.	14,000	130
10:00 a.m.	6,100	150
1:00 p.m.	4,088	125
2:30 p.m.	5,986	110
4:00 p.m.	6,412	150
4:45 p.m.	1,260	200
Average & Total	6,307	865

2. Temperature:

The temperatures of the contents of the anaerobic reactor, the anaerobic pit and the soil surrounding the pit, were determined regularly.

(a) Anaerobic Pit (-5^{o}C):

The temperature in the pit mixed liquor, especially below the surface, rose 1 degree higher than the ambient temperature after every addition of the feed, probably from the heat supplied by the feed waste. However, by next day this levelled off and there was no variation in temperature in the pit, soil and ambient temperatures.

(b) Anaerobic Batch Reactor (+10^{o}C):

The temperature in the anaerobic reactor was the same as ambient temperature in the early part of the experiment. However, later on the temperature in the reactor was 1^{o}C higher than the ambient temperature.

3. pH and Alkalinity:

(a) Anaerobic Pit:

The pH and alkalinity values observed in this

study are shown in Table VIII and IX. No significant fluctuations in both the parameters is evident in the pit.

(b) Anaerobic Batch Reactor:

pH in the anaerobic reactor ($10^{o}C$) dropped by 0.3 units in the first week of operation; this trend is continuing. In six weeks operation, the pH has dropped from 8.98 to 7.6. Alkalinity increased in the first three weeks. From 14.8 g/l it has increased up to 17.6 g/l in the third week. From the third week onward it started decreasing and reached its original value of about 13/0 g/l.

4. Solids:-

(a) Anaerobic Pit:

Total, volatile, dissolved and suspended solids were determined and the results are shown in Table VIII. There appears to be considerable fluctuation in all the solid values of the pit mixed liquor. The difficulty of obtaining uniformly representative samples of the pit contents, owing to its partly frozen condition, is possibly responsible for the fluctuation in results. Also, the variability of the feed samples may be responsible to some extent. No trend of changes in solids concentrations is evident, which indicates no activity in the pit.

(b) Anaerobic Batch Reactor:

Total solids as well as volatile solids have decreased during the six weeks of operation in the anaerobic batch reactor (Table IX). Dissolved solids as well as dissolved volatile solids are also decreasing.

5. Chemical Oxygen Demand (COD):-

(a) Anaerobic Pit:-

Only the centrifuged supernatant of the pit contents was used for COD determinations to avoid the errors introduced by the non-homogeniety of the mixed liquor samples. The results are shown in Table VIII. The COD values are still fluctuating and this may be attributed to the wide variations in the COD contents of the feed waste (Table V). These results also indicate that there is no activity taking place in the pit under the experimental conditions.

TABLE VIII

OPERATIONAL PARAMETERS FOR ANAEROBIC PIT - OPERATED AT -5°C.

Date	pH	Alk. mg/l as $CaCo_3$	Centrifuged Supernatant COD mg/l	Total Solids mg/l	Total Vol. Sol. mg/l	Dissolved Solids mg/l	Dissolv. Vol. Sol. mg/l	Nitrogen - Supernatant			Calorific Value Cal/g.
								TKN mg/l	NH_4-N mg/l	Organic-N mg/l	
20-12-73	8.9	-	43,150	-	-	-	-	10,000	5,320	-	-
12- 2-74	8.7	-	42,240	-	-	55,570	25,220	9,600	6,700	2,800	-
19- 2-74	8.6	21,800	66,000	81,590	57,930	51,080	32,680	9,180	6,220	2,970	3,720
26- 2-74	8.8	17,600	59,810	84,790	66,210	45,160	31,220	7,000	4,260	2,740	-
5- 3-74	8.8	21,200	59,070	86,790	67,720	43,500	30,230	6,830	4,480	2,350	4,180
12- 3-74	8.8	17,000	66,380	86,940	70,070	43,070	31,410	7,930	4,700	3,220	4,370
19- 3-74	8.9	16,600	62,480	81,580	63,650	38,340	25,910	7,620	4,650	2,970	-
Mean	8.8	18,840	56,110	84,160	65,480	47,680	30,150	8,150	5,280	2,720	4,090
Std. Deviation	± 0.05	± 330	± 3,420	± 790	±1,670	±1,720	±2,890	± 2,500	± 2,210	± 260	± 27

TABLE IX

OPERATIONAL PARAMETERS FOR ANAEROBIC REACTOR OPERATED AT 10°C.

Date	pH	Alkal. mg/l $CaCo_3$	Mixed Liquor COD mg/l.	Total Solids mg/l.	Total Volatile Solids mg/l.	Dissolved Solids mg/l.	Dissolved Volatile Solids mg/l.	Nitrogen - Supernatant			Calorific Value Cal/gm.	Centrifuged Supernatant COD mg/l
								TKN mg/l.	NH_4-N mg/l.	Org.-N mg/l.		
5-2-74	8.98	14,800	105,000	68,180	54,300	-	-	7,730	3,470	4,260	4,580	-
12-2-74	8.65	-	107,400	67,520	52,750	43,810	36,740	5,910	3,700	2,210	4,110	42,240
19-2-74	8.45	17,200	117,600	62,900	49,570	25,040	16,330	5,600	4,370	1,030	4,330	45,240
26-2-74	7.9	17,600	117,440	57,300	44,470	25,100	14,980	6,370	5,210	1,160	-	45,720
5-3-74	7.85	14,800	-	60,790	47,630	27,620	17,740	6,050	4,590	1,460	4,340	49,090
12-3-74	7.6	14,200	-	60,400	47,480	25,890	16,500	6,030	4,700	1,330	4,480	52,770
19-3-74	7.8	13,200	-	36,380	25,300	19,910	10,520	5,520	4,540	1,000	-	42,240
Mean	8.2	15,720	111,800	62,850	49,370	29,490	20,460	6,330	4,340	2,020	4,370	46,410
Std. Deviation	± 0.5	± 1560	± 6,400	± 4,270	± 3640	± 8070	± 9150	± 830	± 650	± 1330	± 25	± 1410

(b) Anaerobic Batch Reactor:

COD determinations were made on both mixed liquor and centrifuged supernatant, and the results are shown in Table IX. As expected, COD values of the mixed liquor are erratic probably due to the difficulty of collecting a representative sample. However, the COD values of the centrifuged supernatant are more consistent. These values do not show any COD reductions. It must be remembered that the COD test is somewhat lacking in precision for an individual determination, especially while analyzing waste of very high strength. However, at this initial stage of operation, the reactor probably is in the "acid-formation" phase where complex organic substances are converted to organic acids. COD reductions can be expected when the reactor reaches the methane-formation phase, when these organic acids will be converted to methane gas, which will escape.

6. Nitrogen:-

A knowledge of nitrogen transformations in waste treatment system is important for several reasons. Nitrogen is one of the major nutrients of concern in the eutrophication of water bodies. An efficient means of eliminating nitrogen from wastes can prevent or reduce pollutions of both surface and ground waters.

(a) Anaerobic Pit:

Total Kjeldahl nitrogen (TKN) and NH_4-N were regularly determined for the pit mixed liquor centrifuged supernatant and the results are shown in Table VIII. The nitrogen values in the early weeks of operation are higher than the nitrogen values of the feed waste (about 8,000 mg/l). This may be attributed to the fact that the first sample transferred to the pit was obtained from the "Johnny-on-the-Spot" toilets. This waste sample had significantly higher total nitrogen (10,000 mg/l) compared to 8,000 mg/l in the feed waste collected from the toilet operating in the laboratory. Generally, about two-thirds of the total nitrogen in the pit content is in the NH_4-N form. This is in contrast to only 1/2 of the total nitrogen in the feed waste being in the NH_4-N from Table V. These relative values have stayed approximately constant throughout.

Other parameters measured in this study indicate no bacteriological activity of any kind in the pit. Therefore this change in nitrogen form may be due to some sort of physical phenomenon or the effect of freezing and thawing of the wastes. This will be examined in our future study.

2.0 million/ml. Coliforms ranged from 24 x 10^3/ml to 15 x 10^4/ml, while fecal streptococci occurred in the range of 0.4 million/ml to 2.5 million/ml.

These bacterial counts are far lower than literature values of 10^8 to 10^{10} per gm. of wet faeces, for aerobes, of 10^6 to 10^8/gm for coliforms and 10^4 to 10^8 for enterococci (Mata *et al* 1969) These differences are mainly due to the effect of freezing of the waste. The literature is enormous on the effect of freezing and thawing on bacteria, especially in food technology. However, little work has been done on the effect of low temperature and freezing on bacteria in waste waters. Fournelle (1952) reported that freezing of sewage (-13 to -21^{o}C) brought reductions in total bacterial counts and coliform counts to 95.2% and 99.6% in the first 24 hours. However, fecal streptococci (enterococci) showed reductions in counts ranging from 56% to 72% the first 24 hours of freezing.

(b) Anaerobic Pit:

In general, the microflora (Table XI) in the anaerobic pit exists in the same range as was found in the feed waste, except the coliforms, which have reduced from about 10^4/ml to less than 1/ml. According to Fournelle, the first 24 hours freezing is more detrimental to micro-organisms, and coliforms are more susceptible to freezing than other bacteria. Our results are in agreement with Fournelle in this respect.

Bacterial counts confirm the physical-chemical results which indicated that the anaerobic pit is serving just as a holding tank and no biological activity is taking place.

(c) Anaerobic Reactor:

The results for bacterial counts are shown in Table XII. Total aerobic counts appear to decrease during the first week of operation; however, from the second week onward the bacterial numbers are increasing. The drop in bacterial numbers in the first week seems to be due to the temperature effect. An increase in coliforms also seems to occur. However, fecal streptococci decreased from 1.5 million/ml to 0.055 million/ml after four weeks. It is too early to conclude from this limited data, but the results do indicate that biological activity is going on in the anaerobic reactor under the experimental conditions.

(b) Anaerobic Reactor:

The results for nitrogen determinations are shown in Table IX. It can be seen from the table that about 2,000 mg/l total nitrogen is unaccounted for. The TKN loss continued up to 4 weeks of operation of the reactor. This period corresponds to the high pH values measured in the reactor mixed liquor (8.98 - 7.9). Perhaps the observed nitrogen loss must have occurred by volatilization of NH_3. Chemical equilibrium conditions dictate that free ammonia can exist in solution in appreciable quantities at high pH values.

Organic-nitrogen dropped from 4,000 mg/l to 1,000 mg/l in 5 weeks operation indicating microbial activity in the reactor.

7. Calorific Value:-

Calorific values were determined in order to use these values as another operational parameter as well as to measure the amount of energy produced as a result of the decomposition of the waste. The calorific values of the human waste range from 4,260 to 4,380 cal/g dry wt.

(a) Anaerobic Pit:

The calorific values of the waste content in the anaerobic pit range from 3,720 to 4,370 cal/g dry weight of waste. This indicates no activity in the pit. The fluctuations in the results may be due to the difficulty in collecting the homogeneous sample.

(b) Anaerobic Reactor:

The calorific values of the contents in the anaerobic reactor range from 4,110 - 4,590 cal/g dry weight of waste. It seems this parameter is similar to COD measurement so far as precision is concerned. Probably, it may become of use when the activity is higher in the reactor.

3.2 BACTERIOLOGICAL RESULTS:

Bacteriological tests were conducted regularly on feed waste, anaerobic pit and anaerobic reactor contents, and the results are shown in Table X, XI and XII.

(a) Feed Waste:-

Total aerobic plate count in the feed waste (Table X) ranged from 4 million/ml to 7.0 million/ml. Total anaerobic count ranged from 1.0 million/ml to

In all the samples, irrespective of their source, the total anaerobic bacterial counts were lower than total aerobic counts. This is in agreement with other investigators (Rudolfs *et al* 1926; McKinney *et al*, 1958; McCarty *et al*, 1962); however, these results may be considered as doubtful since incidence of large numbers of obligate anaerobic bacteria in faeces, sewage and sewage treatment processes has been demonstrated by modern culture techniques (Zubrycki and Spaulding, 1962; Post *et al*, 1967, and Toerien *et al*, 1967). Due to the difficulty in obtaining the necessary materials for these modern techniques, we were unable to use them in the present study. However, we are planning to use these modern techniques from now on.

Psychrophilic aerobic bacterial counts were found in the range of 100-300/ml in the feed waste as well as in anaerobic pit contents. No increase in numbers occurred in psychrophilic bacteria in the anaerobic pit during the 6 weeks operation of the pit. The low numbers of psychrophilic bacteria may be attributed to the effect of freezing and thawing. Fournelle (1952) observed a reduction of 99.5-99.9% in psychrophilics after freezing the raw sludge.

TABLE X

MICROFLORA IN HUMAN WASTE

Date	Aerobic Total Count 10^6/ml 20^oC	Anaerobic Total Count 10^6/ml 20^oC	Aerobic Total Count No./ml 0^oC	Entero-cocci 10^6/ml 37^oC	Coliform MPN/ml 37^oC
19-2-74	4.6	-	20×10^3	2.5	24×10^3
26-2-74	7.1	1.91	37×10^4	0.56	11×10^4
5-3-74	5.4	-	44×10^4	0.34	15×10^4
12-3-74	7.5	2.0		0.75	8×10^4
19-3-74	6.3	1.85		1.0	10×10^4

TABLE XI

QUANTITATION OF MICROFLORA IN ANAEROBIC PIT OPERATION AT -5°C

Date	Aerobic Total Count 10^6/ml 20°C	Anaerobic Total Count 10^6/ml 20°C	Aerobic Total Count 10^6/ml 0°C	Entero-cocci 10^6/ml 37°C	Coliform MPN/ml 37°C
12-2-74	7.5	2.4	Nil	0.42	43
19-2-74	7.1	1.7	Nil	0.66	110
26-2-74	-	-	-	-	-
5-3-74	8.9	2.0	Nil	0.85	43
12-3-74	2.83	1.79		0.57	46
19-3-74	0.91	-		1.52	2.4

TABLE XII

QUANTITATION OF MICROFLORA IN ANAEROBIC REACTOR OPERATED AT 10°C

Date	Aerobic Total Count 10^6/ml 20°C	Anaerobic Total Count 10^6/ml 20°C	Aerobic Total Count No./ml 0°C	Fecal Strepto-cocci Count 10^6/ml 37°C	Coliform MPN/ml 37°C
5-2-74	3.38	1.9	200	1.44	
12-2-74	0.75	-	17,000	0.19	0.43
19-2-74	17.5	-	-	0.071	2.40
26-2-74	41.0	1.75	36×10^3	0.069	2400
5-3-74	3,000	150.0	60×10^6	0.055	930
12-3-74	3,200	-		0.027	12
19-3-74	33.5	1.05		0.019	2.4

However, in the anaerobic batch reactor the physchrophilic bacteria increased from 200/ml to 60 x 10^6/ml. This increase corresponds to the increase in mesophilic aerobic bacteria.

In no case were anaerobic psychrophilic bacteria found in this study.

II-4 FUTURE EXPERIMENTAL WORK

1. Effect of Change in Temperature on the Performance of the Anaerobic Pit:-

In order to study the effect of change in temperature on the performance of the anaerobic pit, the temperatures of the unit will be changed every day by 1^oC for 10 days and will be held for about 12 weeks at $+5^oC$. After this the reverse procedure will be used to return to -5^oC. Usual analyses will be conducted. It is hoped that these changes in temperature will simulate the natural seasonal summer fluctuations in temperature in the field.

2. Anaerobic Digestion of Human Waste:-

Anaerobic digestion studies of concentrated human wastes will be continued at 10^oC and for comparison purposes will also be operated at 20^oC. This should provide information on the minimum temperature at which an anaerobic reactor would have to operate in a plant. If found necessary, dilution of the waste will be carried out to decrease the effect of toxic materials, such as high ammonia concentrations. If funds permit, anaerobic digestion studies on more dilute wastes, such as holding tank wastes and black water wastes will be carried out. This may also include further treatment methods of the supernatant through physical-chemical processes such as lime treatment. The extent and range of these future studies will primarily depend on funding available.

3. Effect of Chemical Inhibitors on Anaerobic Digestion:-

A variety of chemicals are added in some communities for the purpose of odor control and as a bacterial killing agent. The potential effect of such practices on the anaerobic treatment process will be investigated.

REFERENCES

Boyd, W.L., and Boyd, J.W. (1967)
Microbiological Studies of Aquatic Habitants of the Area of Inuvik, Northwest Territories, Arctic 20: 27-41

Buswell, A.M. (1957)
Fundamentals of Anaerobic Treatment of Organic Wastes, Sewage Ind. Wastes, 29: 717-721.

Edwards R.
Private Communication. Env. Protection Service, Dept. of Environment, Edmonton.

Fair, G.M., and Moore, E.W. (1934)
Time and Rate of Sludge Digestion and Their Variations with Temperature, Sewage Works J., 6: 1.

Fair, G.M., and Moore, E.W. (1937)
Observations on the Digestion of a Sewage Sludge Over a Wide Range of Temperature, Sewage Wastes J., 9: 1.

Fournelle, H.J. (1952)
Studies of Changes in Sewage Held at Low Temperatures, Alaskan Sci. Conf., 3:74.

Hatting, W.H.J., Kotze, J.P., Thiel, P.G., Toerien, D.F., and Siebert, M.L. (1967)
Biological Changes During Adaptation in an Anaerobic Digester to a Synthetic Substrate, Water Res. 1: 225-277

Heinke, G.W. (1969)
Hydrolysis of Condensed Phosphate in Lake Water and Waste Water, Ph.D. Thesis, McMaster Univ., Hamilton, Ontario.

Hungate, R.E. (1950)
The Anaerobic Mesophilic Cellulolytic Bacteria, Bact. Rev. 14: 1

Imhoff, K. (1906)
Emscherbrunnen, German Patent No. 187723 of 12th May, 1906.

Kotze, J.P., Thiel, P.G., and Hatting, W.H.J. (1969)
Anaerobic Digestion II, Characteristics and Control of Anaerobic Digestion, Water Res. 3: 459-494.

Mata, L.J., Carrillo, C., and Villatore, E. (1969)
Fecal Microflora in Healthy Persons in a Pre-Industrial Region, Appl. Microbiol. 17: 596.

McCarty, P.L., Jeris, J.S., McKinney, R.E., Reed, K., and Vath, C.A. (1962)
Microbiology of Anaerobic Digestion, Report No. R62-29 Sedgewick Lab. Sanit. Sci., Massachusetts, Inst. Technol., Cambridge, Mass.

McCarty, P.L., Jeris, J.S., and Murdoch, W. (1963)
Individual Volatile Acids in Anaerobic Treatment, J. Water Pollut. Control Fed. 35: 1501.

McCarty, P.L. (1964)
Anaerobic Waste Treatment Fundamentals, Part I - Chemistry and Microbiology, Public Works, September, 1964, 107-112.

McGhee, T.J. (1968)
Low-Temperature Anaerobic Digestion, Ph.D. Thesis, Univ. Kansas, Lawrence, Kansas.

McKinney, R.E., Liangley, H.E., and Tomilson, H.D. (1958)
Survival of Salmonella Typhosa During Anaerobic Digestion I, Experimental Methods and High Rate Digestion Studies, Sewage Ind. Wastes, 30: 1469.

McKinney, R.E. (1962)
Microbiology for Sanitary Engineers, McGraw-Hill, New York.

Miyamoto, H. (1972)
Performance Study of the Lagoon at Inuvik, N.W.T., Under Winter Operation, M.A.Sc. Thesis, Dept. Civ. Eng., Univ. Toronto, Toronto.

Mylroie, R.L., and Hungate, R.E. (1954)
Experiments on the Methane Bacteria in Sludge, Can. J. Microbiol. 1: 55

O'Rourke, J.T., and McCarty, P.L. (1967)
Anaerobic Treatment at Reduced Temperature, 4th Ann. Water Pollut. Control Fed. Conf., New York, N.Y.

Pohland, F.G. (1962)
Laboratory Investigations on the Thermological Aspects and Volatile Acids-Alkalinity Behaviour During Anaerobic Sludge Digestion, Ph.D. Thesis, Purdue Univ.

Post, F.J., Allen A.D., and Reid, T.C. (1967)
Simple Medium for the Selective Isolation of Bacteroides and Related Organisms in Sewage, Appl. Microbiol. 15: 213.

Rudolfs, W., Hotchkiss, M., Fisher, A.J. and Lackey, J.B. (1926)
Studies on Fresh Solids Digestion, New Jers. Agric. Expt. Sta. Bull. 427, 50.

Rudolfs, W. (1927)
Effect of Temperature on Sewage Sludge Digestion, Ind. & Eng. Chem. 19.

Siebert, M.L. and Hatting, W.H.J. (1967)
Estimation of Methane-Producing Bacterial Numbers by the Most Probable Number (MPN) Technique, Water Res. 1, 13.

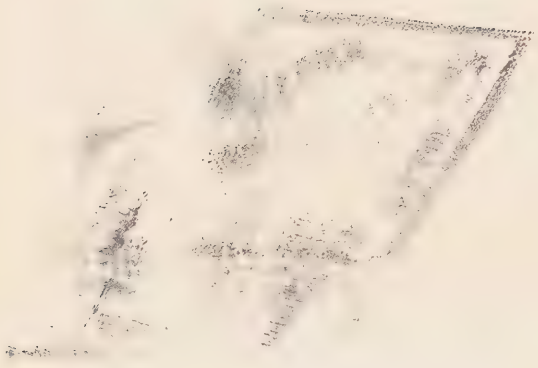
Society of American Bacteriologists (1957)
Manual of Microbiological Methods, p. 112, McGraw-Hill Book Co., New York.

Standard Methods for the Examination of Water and Waste Water (1971), APHA, AWWA, WPCF, 13th Ed., New York, N.Y.

Toerien, D.F., and Siebert, M.L. (1967)
A Method for the Enumeration and Cultivation of Anaerobic "Acid-Forming" Bacteria Present in Digesting Sludge, Water Res. 1, 397.

Toerien, D.F., Siebert, M.L. and Hatting, W.H.J. (1967)
The Bacterial Nature of the Acid-Forming Phase of Anaerobic Digestion, Water Res. 1, 497.

Zeller, A.P.J. (1928)
Effect of Freezing on Sludge Digestion, New Jers. Agric. Expt. Sta. Bull. No. 486 (1928).

Zubrycki, L., and Spaulding, E.H. (1962)
Studies on the Stability of the Normal Faecal Flora. J. Bact. 83: 968.

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